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(54) **TRANSFORMER FOR MEASURING A COMMON MODE CURRENT AND METHOD OF DETERMINING A COMMON MODE CURRENT**

TRANSFORMATOR ZUR MESSUNG EINES GLEICHTAKTSTROMS UND VERFAHREN ZUR BESTIMMUNG EINES GLEICHTAKTSTROMS

TRANSFORMATEUR POUR MESURER UN COURANT DE MODE COMMUN ET PROCÉDÉ DE DÉTERMINATION D’UN COURANT DE MODE COMMUN

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(56) References cited:
EP-A1- 0 137 347
EP-A1- 2 749 891
EP-A1- 2 924 450
WO-A1-2006/048020
WO-A2-2012/160233
DE-A1- 3 940 932
FR-A1- 2 987 515
US-A- 4 274 051
US-A- 4 278 940
US-A- 4 616 174
US-A- 5 327 065

• **Zhigang Zhao ET AL: "The optimization of dual-core closed-loop fluxgate technology in precision current sensor", Journal of Applied Physics, 7 March 2012 (2012-03-07), pages 07E722-07E722-3, XP055224698, DOI: 10.1063/1.3677200 Retrieved from the Internet: URL:http://scitation.aip.org/deliver/fulltext/aip/journal/jap/111/7/1.3677200.pdf**

Description

TECHNICAL FIELD

[0001] Embodiments relate generally to systems, methods, and devices for safe charging, and more particularly to residual current detection (RCD) and ground monitor interrupter (GMI).

BACKGROUND

[0002] Residual current detection (RCD) and ground monitor interrupter (GMI) are essential functions for safe charging of electric vehicles. The RCD is responsible for interrupting AC power should a conduction path to ground appear in the charging circuit. For example, a person touching live components of an electric vehicle (EV) may cause a conduction path to ground.

[0003] The GMI ensures that the ground connection between the EV charger and a utility is continuous and of low impedance. The GMI interrupts AC power to the EV if the ground connection is noncontinuous or has high impedance. High impedance or open ground connections may result in dangerous high voltages appearing on the chassis of the EV.

[0004] From DE 39 40 932 A1 a measurement transducer with two soft magnetic sensor cores is known, which are acted upon by a magnetic field and has modulation coils causing opposing magnetization of the cores and a detection winding. A periodic, symmetrical modulation current is fed to the modulation coils so that the core hysteresis curves are driven well into saturation.

[0005] Zhigang Zhao et al: "The optimization of dual-core closed-loop fluxgate technology in precision current sensor", (2012), discusses a dual-core closed-loop flux gate current sensor, wherein ultra low nonlinear error and low offset error are obtained.

[0006] From WO 2006/048020 A1 a detector circuit for measuring relatively strong currents using a plurality of transformers is known. WO 2012/160233 A2 discloses a charger and method for measuring charging current for electrical vehicles.

[0007] EP 0 137 347 A1 discloses a detector circuit for current measurements, wherein for the measurement of large currents a zero-flux current transformer is used based on two identically wound toroidal cores. From EP 2 749 891 A1 a current sensor is known having two cores that are connected in series to generate a magnetic flux in surrounding directions opposite to each other in the two cores.

[0008] US 4,274,051 discloses a line current measuring arrangement employing two matched toroidal cores with line windings, control windings, sense windings, and feedback windings.

[0009] Conventional methods for detecting residual leakage current rely on current transformers, which may be sensitive to AC leakage currents, but can saturate and fail to operate should DC leakage current be present. EV and solar installations may contain dangerously high DC voltages that may cause DC leakage current to be present.

SUMMARY

[0010] The invention provides a transformer according to independent claim 1 and a method of determining a common mode current according to independent claim 7. Advantageous embodiments are defined by the dependent claims.

[0011] In additional device embodiments, a net flux through the sense winding may be zero if no common mode current is present on the one or more utility lines. A saturation flux density of the first core may be substantially equal to the saturation flux density of the second core. A saturation flux density of the first core may be within 10% of the saturation flux density of the second core.

[0012] The first drive winding may apply a high frequency signal to the one or more utility lines and the second drive winding may measure an amplitude of a current that results, where the amplitude of the current that results may be proportional to a reciprocal of a ground loop impedance. The common mode current in the utility line may be at least one of: an AC residual leakage current and a DC residual leakage current. The first core may be disposed substantially parallel to the second core.

[0013] In additional method embodiments, a saturation flux density of the first core may be substantially equal to the saturation flux density of the second core. A saturation flux density of the first core may be within 10% of the saturation flux density of the second core.

[0014] Additional method embodiments may include: measuring one or more peaks of a rising edge of the sensed one or more pulses by a first sample and hold circuit; measuring one or more peaks of a falling edge of the sensed one or more pulses by a second sample and hold circuit; determining a difference in magnitude between an average of the peaks of the rising edges and an average of the peaks of the falling edges; and adjusting at least one of: the first high frequency square wave current and the second high frequency square wave current based on the determined difference in magnitude, where the adjusted current may compensate for a difference in a saturation flux density between the first core and the second core. Method embodiments may also include: providing a high frequency signal to the one or more utility lines by the first drive winding; and measuring an amplitude of a current that results by the second drive winding, where the amplitude of the current that results may be proportional to a reciprocal of a ground loop impedance. The high frequency signal driven by the first drive winding may flow to a utility ground, to an electric vehicle service equipment (EVSE) through a ground wire, to ground filter capacitors of the EVSE and to ground filter capacitors of an electric vehicle (EV), to the second core, and to the first core. No signal may be measured by the second core if a resistance of the utility ground is too high or open. The common mode current in the utility line may be at least one of: an AC residual leakage current and a DC residual leakage current.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principals of the invention. Like reference numerals designate corresponding parts throughout the different views. Embodiments are illustrated by way of example and not limitation in the figures of the accompanying drawings, in which:

FIG. 1 depicts an electrical diagram of an exemplary transformer for detecting residual leakage current;
FIG. 2 depicts an exemplary transformer for detecting residual leakage current having two cores shown side-by-side;
FIG. 3 depicts a graph of voltage on an exemplary sense winding and current in exemplary drive windings as cores of an exemplary transformer are driven in and out of saturation;
FIG. 4 depicts two sample and hold circuits for an exemplary sense winding;
FIG. 5 depicts an idealized B-H curve of two poorly matched cores of a transformer driven in unison;
FIG. 6 depicts a graph of drive current and voltage on a sense winding for two poorly matched cores of a transformer driven in unison;
FIG. 7 depicts a B-H curve of two well-matched cores of a transformer driven in unison;
FIG. 8 depicts a graph of drive current and voltage on a sense winding for two well-matched cores of a transformer driven in unison with a DC leakage current present;
FIG. 9 depicts an exemplary circuit for balancing two cores of a transformer with individual drive currents;
FIG. 10 depicts a circuit of exemplary drive winding drivers;
FIG. 11 depicts an exemplary flip flop circuit for changing polarity on a drive command signal and its inverse;
FIG. 12 depicts a circuit of an exemplary compensation winding of a transformer;
FIG. 13 depicts a circuit of an exemplary ground loop of an electric vehicle supply equipment (EVSE);
FIG. 14 depicts a circuit of an exemplary ground impedance monitoring (GMI) detector;
FIG. 15 depicts a graph of drive current, output voltage on a sense winding, and drive voltage of a transformer with well-matched cores and no current applied;
FIG. 16 depicts a graph of drive current, output voltage on a sense winding, and drive voltage of a transformer with well-matched cores and 6mA current applied;
FIG. 17 depicts a graph of drive current, output voltage on a sense winding, and drive voltage of a transformer with unmatched cores and no current applied;
FIG. 18 depicts a graph of drive current, output voltage on a sense winding, and drive voltage of a transformer with unmatched cores and 6mA current applied;
FIG. 19 depicts a circuit for generating a square wave for drive windings of a transformer;
FIG. 20 depicts two sample and hold circuits for an exemplary sense winding;
FIG. 21 depicts a circuit of an exemplary compensation controller of a transformer;
FIG. 22A depicts a graph of a sensor input and output for a 60Hz sinewave;
FIG. 22B depicts a graph of a sensor input and output for a 60Hz triangle wave;
FIG. 22C depicts a graph of a sensor input and output for a 0.6Hz square wave;
FIG. 23 depicts a graph of a sense winding signal caused by an external magnetic field;
FIG. 24 depicts a graph of a leakage current producing a common mode signal;
FIG. 25 depicts an exemplary shielding of an exemplary transformer to contain electromagnetic interference (EMI);
FIG. 26 depicts a circuit of an exemplary H-bridge driver;
FIG. 27 depicts a circuit of an exemplary compensation winding driver;
FIG. 28 depicts a circuit of an adjustable drive voltage;
FIG. 29 depicts a circuit for signal conditioning an exemplary sense winding signal;
FIG. 30 depicts an exemplary alternate transformer having a window for a fluxgate;
FIG. 31 depicts a flowchart of an exemplary residual current detecting (RCD) method;
FIG. 32 depicts a flowchart of an exemplary ground monitor interrupter (GMI) method; and
FIG. 33 depicts an exemplary system having residual current detecting (RCD) and ground monitor interrupter (GMI) to cut power between a utility and an electric vehicle if a fault is detected.

DETAILED DESCRIPTION

[0016] The present system allows for a DC and AC sensitive transformer for detection of residual leakage current, and associated drive circuitry, which is also able to measure the impedance of the ground connection. The system can measure leakage currents as small as 6mA with sub milliamp accuracy in the presence of charging currents as high as 80A.

[0017] FIG. 1 depicts an electrical diagram 100 of an exemplary transformer for detecting residual leakage current. The transformer includes two saturable magnetic cores 102, 104. The cores may be made of a highly "square" magnetic material such as permalloy, metglass, supermalloy, nanoperm, mu-metal, etc. The transformer also includes one or more primary conductors 106. The transformer measures the common mode current on the one or more primary conductors 106. A compensation winding 108 may be wound on both cores 102, 104. The compensation winding 108 may be used to linearize the measurement of the common mode current. A sense winding 110 may also be wound on both cores. The sense winding may be used to determine a magnitude and direction of the common mode current on the one or more primary conductors 106. The transformer may also include a first drive winding 112 on the first core 102 and a second drive winding 114 on the second core 104. The drive windings 102, 104 may be used to drive their respective cores 102, 104 in and out of saturation. The drive windings 102, 104 may also be used to perform ground monitor interrupter (GMI) source and residual current detection (RCD) functions.

[0018] FIG. 2 depicts an exemplary transformer 200, not according to the invention, for detecting residual leakage current having two cores 202, 204 shown side-by-side. A first core 202 and a second core 204 may be made from a square hard saturating material, such as permalloy or metglass. The first core 202 and the second core 204 should reasonably well matched, particularly their saturation flux densities (Bmax). A first drive winding 206 is wound on the first core 202. A second drive winding 208 is wound on the second core 204. A sense winding 210 is wound across both cores 202, 204. A compensation winding 212 is also wound across both cores 202, 204. A utility line 214 is threaded through the middle of both cores 202, 204. The utility line 214 may be an AC conductor of an electric vehicle supply equipment (EVSE). The transformer 200 may be placed about the utility line 214 between a utility power source 222 and an electric vehicle (EV) 224. The magnetic field direction 218 of the first core 202 and the magnetic field direction 220 of the second core 204 are shown with arrows.

[0019] The cores 202, 204 are displayed side-by-side for illustration purposes. In some embodiments, the cores 202, 204 may be stacked on top of one another such that the first core 202 is substantially parallel to the second core 204.

[0020] The transformer 200 may provide residual current detection (RCD) functionality. Each of the drive windings 206, 208 may be driven with a high frequency square wave current 216. The current 216 may drive the cores 202, 204 into saturation. Once the cores saturate, the polarity of the drive current 216 may be reversed. As a result, the net flux through the sense winding 210 is zero since the flux from the drive currents 206, 208 is identical in the first core 202 and the second core 204, but of opposite polarity.

[0021] When a common mode, or leakage, current is present in the utility line 214, it adds to the flux in one core and subtracts from the flux in the other. This change in flux will cause one core to saturate before the other core, and the flux through the sense winding 210 no longer cancels. When one core saturates and the other doesn't saturate, the current in the drive windings 206, 208 will couple through the non-saturated core into the sense winding 210. Pulses will appear on the sense winding 210 every time the cores 202, 204 are driven into saturation. The amplitude and polarity of the pulses are indicative of the common mode current on the utility line 214.

[0022] FIG. 3 depicts a graph 300 of voltage on an exemplary sense winding 302 and current in exemplary drive windings 304 as cores of an exemplary transformer are driven in and out of saturation.

[0023] FIG. 4 depicts two sample and hold circuits 400 for an exemplary sense winding. In RCD mode, the sense winding 402 is connected through a switch 404 to a burden resistor 406 and an amplifier 408. The voltage of the peaks on the sense winding, as shown in FIG. 3, is measured by two sample and hold (S/H) circuits 410, 412 that are alternately triggered by the rising edge the drive command signal 414, as shown in FIG. 3. The acquisition time of the S/H 410, 412 is matched to a pulse width of pulses on the sense winding 402.

[0024] FIG. 5 depicts an idealized B-H curve 500 of two poorly matched cores 502, 504 of a transformer driven in unison. The B-H curve shows the relationship between magnetic flux density (B) and magnetic field strength (H) for each of the core 502, 504 materials. The first core 502 has a higher saturation flux density (Bsat) than the second core 504. Therefore, the first core 502 saturates later than the second core 504. A drive current on the first core 502 would couple into a sense winding of the transformer every time the cores 502, 504 saturate.

[0025] The disclosed transformer relies on the flux in the two cores being substantially equal, and so the cores need to be reasonably well matched, particularly their saturation flux density (Bmax). If the cores are not well matched, a spurious signal may appear on the sense winding even when there is no current flowing in the primary conductors. Temperature variation, age related drift, and external magnetic fields may cause similar spurious signals. These spurious signals must be detected and compensated for to prevent offsets in the leakage current measurement.

[0026] The signal from mismatched cores is different from a signal from an actual current flowing on the primary. In the case of a core mismatch, the core with the lower saturation flux density (Bsat) will always saturate first regardless of drive polarity, as long as there's no current in the primary. Having one core saturate before the other will result in the drive current from the other core coupling into the sense winding every time the core saturates. Since the drive current alternates between positive and negative, this will result in pulses on the sense winding of alternating polarity.

[0027] FIG. 6 depicts a graph 600 of drive current 602 and voltage 604 on a sense winding for two poorly matched cores of a transformer driven in unison. Mismatched cores, temperature drift and external magnetic fields may cause pulses of alternating polarity on the sense winding when the two cores of the transformer saturate.

[0028] FIG. 7 depicts a B-H curve 700 of two well-matched cores 702, 704 of a transformer driven in unison. Two well-matched cores 702, 704 are shown in the presence of a common mode current on the primaries. When a positive drive current (H) is applied, the second core 704 saturates first and a drive current couples into the sense winding through the first core 702. When a negative drive current (H) is applied, the first core 702 saturates first and a drive current couples through the second core 704. The second core 704 is wound with opposite polarity from the first core 702 so the resulting pulse on the sense winding is again positive.

[0029] For matched cores 702, 704 in the presence of a common mode current on the primary, the core that saturates will alternate depending on the drive current direction. This alternating saturation results in the current in the first drive winding and the current in the second drive winding alternatingly coupling into the sense winding. The two drive windings are wound in opposing directions so the end result is that the pulses in the sense winding are of the same polarity.

[0030] FIG. 8 depicts a graph 800 of drive current 802 and voltage 804 on a sense winding for two well-matched cores of a transformer driven in unison with a DC leakage current present. A common mode current in primary conductors results in pulses of the same polarity when the cores saturate.

[0031] FIG. 9 depicts an exemplary circuit 900 for balancing two cores of a transformer with individual drive currents. Both cores will never be perfectly matched. Compensating for some degree of mismatching between the cores may be achieved by driving the two cores with individual drive current. The core with the lower saturation flux density (Bsat) may be driven with less current than the core with higher Bsat. By varying the current to each of the cores based on their Bsat, both cores may be made to saturate at the same time and spurious signals may be eliminated or greatly reduced. Magnetic field (H) (At/m) is a function of current, and current through an inductor is a function of the product of voltage and time (Vs). Regulating the voltage that is applied to the drive winding allows for compensating for differences in Bsat between the two cores.

[0032] FIG. 10 depicts a circuit 1000 of exemplary drive winding drivers. A proportional-integral-derivative (PID), or similar, controller may be used to regulate out a difference in magnitude between two pulses measured by the sample and hold circuit as shown in FIG. 4.

[0033] An output of the balance controller 1002, as shown in FIG. 9, may be added 1004 to the magnitude of a drive command signal 1008 of one core, and subtracted from 1006 the magnitude of a drive command signal 1010 of the other core. The drive commands 1008, 1010 may be fed through selector switches 1012, 1014 to output drive buffers 1016, 108 that feed the drive windings 1020, 1022 through current limiting resistors 1024, 1026. The current through each drive winding 1020, 1022 is measured 1028, 1030; rectified; and sent to a comparator 1032, 1034 that compares it against a saturation threshold. When the drive current magnitude is higher than the set threshold, the core has saturated and the output of the comparator 1032, 1034 goes high.

[0034] FIG. 11 depicts an exemplary flip flop circuit 1100 for changing polarity on a drive command signal and its inverse. The output of the two comparators causes a flip flop circuit to change polarity on the drive command signal (Drive) and it's inverse (! Drive).

[0035] FIG. 12 depicts a circuit 1200 of an exemplary compensation winding of a transformer. The amplitude and polarity of the pulses on a sense winding of the transformer give an indication of the common mode current flowing on primary conductors. Due to the nonlinear nature of magnetic cores, the pulses on the sense winding do not provide an accurate measurement. In order to get an accurate measurement, a compensation winding 1202 is required. The current in the compensation winding 1202 is adjusted until the pulses on the sense winding go away, which can only happen when the current in the compensation winding 1202 perfectly matches the common mode current in the primary conductors. The primary current can therefore be calculated as the current in the compensation winding multiplied by the turn ratio between the two.

[0036] A PID, or similar, controller may be used to regulate out the average voltage of the pulses on the sense winding. The output of a regulator may be used to control a current source that drives a current through the compensation winding 1202 in RCD mode. The leakage current 1204, or the common mode current, in the primary conductors may be accurately determined as the output of the regulator multiplied by the turn-ratio of the compensation windings 1202 to the primary windings.

[0037] FIG. 13 depicts a circuit 1300 of an exemplary ground loop of an electric vehicle supply equipment (EVSE) 1301. For safety reasons, regulatory agencies, such as UL headquartered in Northbrook, IL, requires the EVSE 1301 to verify that the EVSE 1301 and an electric vehicle (EV) 1302 are both properly grounded 1304. The ground connection 1304 between vehicle 1302 and EVSE 1301 may be verified by a pilot handshake signal, such as that specified in SAE J1772. A ground resistance 1306 between a utility 1308 and the EVSE 1301 must however be verified by other means.

[0038] In ground monitor interrupter (GMI) mode, the fluxgate transformer may be reconfigured as a signal generator and detector. A first core of the transformer and its respective drive winding 1310 may be used to apply a high frequency signal to the utility lines 1312, 1314. The second core of the transformer and its respective drive winding 1316 may be used to measure the amplitude of a current that results. The amplitude of the resulting current is proportional to a reciprocal of the ground loop impedance.

[0039] The high frequency current generated by the first drive winding 1310 flows through the utility transformer into ground 1304; back to the EVSE through the ground wire 1318; to ground filter capacitors 1320, 1322, 1324 of the EVSE 1301 and EV 1302, respectively; through the second core and back to the first core. If the resistance of the ground connection is too high, or open, no current can flow and no signal will be measured by the second core.

[0040] During the GMI test, the sense winding and compensation winding must be open circuit, which is accomplished by selector switches 1326, 1328. The drive circuit for the first drive winding 1310 is switched over to a high frequency signal source. The drive circuit for the second drive winding 1316 is held in a high impedance state.

[0041] FIG. 14 depicts a circuit 1400 of an exemplary ground impedance monitoring (GMI) detector. The second drive winding 1316 is also connected to a detector circuit 1400 through DC blocking capacitors 1402, 1404.

[0042] An amplifier 1406 buffers the signal from the drive winding 1316 and feeds it through a bandpass filter 1408 with a center frequency around the high frequency source feeding the first drive winding 1316. The filtered signal is fed to a mixer 1410, the local oscillator input 1412 of which is fed by a high frequency signal. The high frequency signal 1412 is the same frequency as the drive, but with a different phase shift. The output of the mixer is integrated 1413 in order to measure the resulting DC signal magnitude. The output of the integrator 1414 is now proportional to the reciprocal of the ground loop impedance. The capacitive or inductive nature of the ground impedance can be determined by adjusting the phase shift of the local oscillator 1412.

[0043] FIG. 15 depicts a graph 1500 of drive current 1502, output voltage 1504 on a sense winding, and drive voltage 1506 of a transformer with well-matched cores and no current applied. For a matched core test, a sensor was constructed from a pair of well matched cores (<0.5%). The drive winding may have 10 turns per core, the sense winding have may 10 turns, and a primary wire may be fed through the opening of both cores to measure the DC current in the primary wire. The drive winding is driven from a function generator at 10kHz through a DC blocking capacitor and a 10 ohm resistor for measuring current. The output voltage 1504 is close to 0 as the flux in the two cores cancel.

[0044] FIG. 16 depicts a graph 1600 of drive current 1602, output voltage 1604 on a sense winding, and drive voltage 1606 of a transformer with well-matched cores and 6mA current applied. A significant output voltage 1604 can be seen on the sense winding when the fault current is applied, as compared to the output voltage on the sense winding with no current applied as in FIG. 15.

[0045] FIG. 17 depicts a graph 1700 of drive current 1702, output voltage 1704 on a sense winding, and drive voltage 1706 of a transformer with unmatched cores and no current applied. With no DC fault current applied, the unmatched cores produce noticeably greater signal amplitude than the matched cores, as shown in FIG. 15. The cores shown in graph 1700 have a matching error of 10%. Ideally, the cores may have a matching error of 5% or lower, but the cores may be balanced with a matching error of up to 10%. The transformer with these unmatched cores has twenty-turn drive windings, twenty-turn sense windings, and a single turn compensation winding on only one of the cores.

[0046] FIG. 18 depicts a graph of drive current 1802, output voltage 1804 on a sense winding, and drive voltage 1806 of a transformer with unmatched cores and 6mA current applied. With 6mA of DC fault current applied, the unmatched transformer produces less symmetrical output for rising and falling transition than the matched sensor, as shown in FIG. 16, but the signal amplitude remains significant. The most consistent signal component is the rapid transition of the drive current 1802 and output voltage 1804 around the rising edge of the drive voltage 1806 waveform. This signal may be fully and consistently canceled by adjusting the current in the compensation winding.

[0047] In some embodiments, the transformer may be subject to variations in temperature. After being heated for five minutes, the signal remained consistent. If anything, the amplitude of the signal became more symmetrical at the rising and falling edges. The compensation current necessary to cancel the output remained consistent with no significant (<10%) drift at 6mA fault current. Both cores of the transformer tend to change temperature at the same rate due to their proximity and so any variations are largely cancelled out.

[0048] FIG. 19 depicts a circuit 1900 for generating a square wave for drive windings 1901, 1903 of a transformer. An analog device may be constructed to generate a signal for the drive windings using: a quad operational amplifier (op-amp) 1902; a sample and hold integrated circuit (IC) 1904; transistors 1906, 1908; potentiometers 1910, 1912 for tuning; resistors 1914, 1916, 1918, 1920, 1922; and capacitors 1924.

[0049] The drive circuit 1900 generates the square wave for the drive windings 1901, 1903. The op-amp 1902 used as a comparator applies a voltage to the drive windings 1901, 1903 through a buffer. When the cores saturate, the current rises rapidly and the voltage across Rsense 1922 exceeds the trip threshold for the comparator, which then trips and reverses the output voltage. This arrangement ensures that the cores are always driven to the same level of saturation regardless of supply voltage variations or core parameters.

[0050] A second comparator 1904 with an adjustable trip threshold is used to generate the sample pulse for the sample and hold circuit. The second comparator 1904 may be adjusted to trip just before the first comparator. The potentiometer 1910 is connected in parallel with the drive windings 1901, 1903, which makes it possible to compensate for the effect of poorly matched cores. The amount of current through each core can be adjusted so that the cores always saturate at the same time.

[0051] FIG. 20 depicts two sample and hold circuits 2000 for an exemplary sense winding 2002. A single sample and hold integrated circuit (IC) 2004 may be very sensitive to external magnetic fields and temperature drift. A second sample and hold IC 2006 allows both a rising edge 2008 and a falling edge 2010 of a pulse 2012, 2014 to be sampled. The average of the rising edge 2008 and the falling edge 2010 may be fed to a proportional-integral (PI) regulator.

[0052] FIG. 21 depicts a circuit 2100 of an exemplary compensation controller of a transformer. The PI regulator tries to cancel out the signal from the sense winding by running a current through a compensation winding 2102, the current through the compensation winding 2102 is proportional to the DC leakage current when the PI error is zero. The voltage across the burden resistor Rburden 2104 is therefore a direct measurement of the leakage current.

[0053] FIG. 22A depicts a graph 2200 of a sensor input 2206 and output 2208 for a 60Hz sinewave. FIG. 22B depicts a graph 2202 of a sensor input 2210 and output 2212 for a 60Hz triangle wave. FIG. 22C depicts a graph 2204 of a sensor input 2214 and output 2216 for a 0.6Hz square wave. The transformer is able to measure up to 600Hz without significant reduction in gain, and better tuning of the PI could improve that further.

[0054] FIG. 23 depicts a graph 2300 of a sense winding voltage 2302 and current 2304 signals caused by an external magnetic field. The transformer may be sensitive to external magnetic fields. External magnetic fields may have the same effect as poorly matched cores and temperature drift. External magnetic fields produce a differential signal between rising and falling edge pulses.

[0055] FIG. 24 depicts a graph 2400 of a leakage voltage 2402 and current 2404 signals producing a common mode signal. The leakage signals 2402, 2404 produces a common mode signal. Adding a second sample and hold IC and regulating the average of the two pulses drastically reduces sensitivity to core matching, temperature drifts, and external fields. The differential signal caused by external fields may be tuned out using a core balance potentiometer. Dynamic control over the core balancing allows for tuning of the cores in response to changing external conditions. Tuned cores may produce less noise on the AC line and may be less susceptible to the noise on the AC line. Using two sampling circuits may eliminate spurious signals from core mismatch, temperature drift, and external magnetic fields.

[0056] FIG. 25 depicts an exemplary shielding 2500 of an exemplary transformer 2502 to contain electromagnetic interference (EMI). A magnetic shield 2500 made of soft iron may be placed around the transformer 2502 to reduce and/or eliminate spurious signals caused by external magnetic fields. A cylindrical shield, such as a steel pipe, may be placed around the transformer 2502 to reduce the effects of external magnetic fields by an order of magnitude. The shielding 2500 may also contain any EMI caused by the constant switching of the drive windings and saturating cores. The magnetic shield 2500 greatly reduces sensitivity to external magnetic fields.

[0057] FIG. 26 depicts a circuit 2600 of an exemplary H-bridge driver. An I DriveX signal is a measurement of the drive current and may be fed to an analog comparator. A drive winding driver may use an off-the-shelf H-bridge. This circuit 2600 may not have GMI capability.

[0058] FIG. 27 depicts a circuit 2700 of an exemplary compensation winding driver. A compensation winding current may be precisely controlled, as it provides the measurement of the leakage current. The circuit 2700 takes a pulse width modulation (PWM) proportional to desired current where 50% = 0 current as its input. The PWM is applied to R2 2702. The filtered voltage across R4 2704 sets the current through the Rload 2706, which is the compensation winding. R3 2708 provides a minimum impedance and improves the effect of the filter capacitor C5 2710. R5 2712 and R6 2714 set the 0 current point. Rload 2706 is the compensation winding. This circuit 2700 may not have GMI functions.

[0059] FIG. 28 depicts a circuit 2800 of an adjustable drive voltage. The drive voltage for each core may be adjustable in order to compensate for core matching and drift. Each H bridge IC may supplied by a LM317 regulator 2802. The processor may reduce the output voltage of the regulator by PWM. The output voltage may be adjusted from 8-12V. Adjusting the output voltage may be used to adjust the drive voltage for the drive winding, using an adjustable voltage regulator to feed the H-bridge.

[0060] FIG. 29 depicts a circuit 2900 for signal conditioning an exemplary sense winding signal. A sense winding is connected to a 100 ohm burden resistor 2902, which may be biased at a VCC midpoint using a resistive/capacitive divider. The voltage across the burden resistor 2902 may spike up to +-1V during normal operation. A Schottky diode 2904 protects an ADC input 2906 from abnormal spikes. This circuit 2900 may not have GMI functionality.

[0061] FIG. 30 depicts an exemplary alternate transformer 3000, not according to the invention, having a window 3002 for a fluxgate. This transformer 3000 may not have a GMI mode. The transformer 3000 may have a magnetic core 3004 of a high mu material with the window 3002 for a fluxgate cut into it. The window 3002 goes through the entire magnetic core 3004. A fluxgate drive winding 3006 may saturate the left and right halves of the window at 10 kHz with opposite polarities. The drive winding 3006 may be present on each leg 3014, 3016 of the window 3002. There may be about twenty turns of the drive winding 3006 on each leg 3014, 3016 of the window. In the presence of a magnetic field caused by DC leakage current in a utility line 3008, a pulsating voltage appears on a sense winding 3010. The leakage current adds to the flux of one of the legs 3014 and subtracts from the flux of the other leg 3016, which results on a voltage on the sense winding 3010. The sense winding 3010 may be wound across both legs of the magnetic core 3004, but not through the window 3002. The Earth's magnetic flux may not significantly affect the reading (0.1-0.2%). This transformer is small, inexpensive, has a simple installation requiring only one turn of the utility line 3008, it is EMI immune and has low emissions, it has a high bandwidth and will measure AC leakage and DC leakage, and has a low sensitivity to external magnetic fields.

[0062] A compensation winding 3012 may be driven by a microprocessor to cancel out the voltage. Any pulses on the sense winding 3010 may be provided to a microprocessor so that they may be cancelled out by the compensation winding 3012. The microprocessor may determine a leakage current on the utility line 3008 as the amount of compensation current needed in the compensation winding 3012 to cancel out the pulses on the sense winding 3010 is equal to the leakage current on the utility line 3008.

[0063] FIG. 31 depicts a flowchart of an exemplary residual current detecting (RCD) method 3100. The method 3100 may include providing a first high frequency square wave current to a first drive winding wound on a first core (step 3102). The method may also include providing a second high frequency square wave current to a second drive winding wound on a second core (step 3104). The second high frequency square wave current may have an opposite polarity of the first high frequency square wave current. The method 3100 may then include sensing one or more pulses on a sense winding wound about the first and second cores (step 3106). The one or more pulses may be created by a common mode current on one or more utility lines threaded through the first and second cores. The method 3100 may then include adjusting a current to a compensation winding wound about the first and second cores to cancel out the one or more pulses on the sense winding (step 3106). The method 3100 may then include determining the common mode current on the one or more utility lines as the current on the compensation winding multiplied by a turn ratio between the compensation winding and the sense winding (step 3108).

[0064] In some embodiments, a saturation flux density of the first core may be substantially equal to the saturation flux density of the second core. In other embodiments, a saturation flux density of the first core is within 10% of the saturation flux density of the second core. If the first core has a lower saturation flux density than the second core, then the first drive winding may be provided with less current than the second drive winding such that the first core saturates at substantially the same time as the second core. One or more peaks of a rising edge of the sensed one or more pulses may be measured by a first sample and hold circuit. One or more peaks of a falling edge of the sensed one or more pulses may be measured by a second sample and hold circuit. A difference in magnitude between an average of the peaks of the rising edges and an average of the peaks of the falling edges may be determined. At least one of: the first high frequency square wave current and the second high frequency square wave current may be adjusted based on the determined difference in magnitude, and the adjusted current may compensate for a difference in a saturation flux density between the first core and the second core. The common mode current in the utility line may be at least one of: an AC residual leakage current and a DC residual leakage current.

[0065] FIG. 32 depicts a flowchart of an exemplary ground monitor interrupter (GMI) method 3200. The method 3200 may include providing a high frequency signal to one or more utility lines by a first drive winding (step 3202). The method 3200 may also include measuring an amplitude of a current that results by the second drive winding (step 3204). The amplitude of the current that results may be proportional to a reciprocal of a ground loop impedance. The high frequency signal driven by the first drive winding may flow to a utility ground, to an electric vehicle service equipment (EVSE) through a ground wire, to ground filter capacitors of the EVSE and to ground filter capacitors of an electric vehicle (EV), to the second core, and to the first core. If a resistance of the utility ground is too high or open, then no signal may be measured by the second core.

[0066] FIG. 33 depicts an exemplary system 3300, not according to the invention, having residual current detecting (RCD) and ground monitor interrupter (GMI) to cut power between a utility 3302 and an electric vehicle (EV) 3304 if a fault is detected. The system may include an electric vehicle supply equipment (EVSE) 3306 to charge the EV 3304 with power provided by the utility 3302. While this system is described with reference to an EVSE, it may be applied to other electrical systems requiring RCD and GMI capabilities, such as a wall socket in a building. The EVSE may include a current sensing transformer 3308. The transformer may include a first core; a first drive winding wound on the first core; a second core; a second drive winding wound on the second core; a sense winding wound across the first and second cores; and a compensation winding wound across the first and second cores. The first and second cores may be arranged substantially parallel to one another. A saturation flux density of the first core may be substantially equal to the saturation flux density of the second core. One or more utility lines 3314, 3316, depicted as solid lines and dashed lines in the EVSE 3306, may be threaded through a middle of the first and second cores of the transformer 3308.

[0067] In RCD mode, a microcontroller 3310 may drive the first drive winding with a first high frequency square wave current. The microcontroller 3310 may also drive the second drive winding with a second high frequency square wave current. The second high frequency square wave current may have an opposite polarity of the first high frequency square wave current. A common mode current, such as an AC residual leakage current and/or a DC residual leakage current, in the one or more utility lines 3314, 3316 may cause one or more pulses to appear on the sense winding of the transformer 3308. These pulses may be detected by the microcontroller 3310. In response to the pulses, a current on the compensation winding of the transformer 3308 is adjusted by the microcontroller 3310 until the one or more pulses on the sense winding of the transformer 3308 are cancelled out. The microcontroller may determine the common mode current on the one or more utility lines 3314, 3316 as the adjusted current on the compensation winding of the transformer 3308 multiplied by a turn ratio between the compensation winding and the sense winding of the transformer 3308.

[0068] The microcontroller 3310 may determine if the common mode current exceeds a set threshold. The microcontroller 3310 may send a signal to a relay 3312 to cut power between the EVSE 3306 and/or the EV 3304 and the utility 3302 when the determined set threshold is exceeded. The threshold may be 6mA for DC current and 20mA for AC current. The thresholds may be varied based on the application and any laws set by regulatory agencies.

[0069] In GMI mode, the microcontroller 3310 may drive the first drive winding of the transformer 3308 with a high frequency signal to the one or more utility lines 3314, 3316. The second drive winding of the transformer 3308 may measure an amplitude of a current that results, which may be proportional to a reciprocal of a ground loop impedance. wherein the high frequency signal driven by the first drive winding flows to a utility ground, to the EVSE through a ground wire, to ground filter capacitors of the EVSE and to ground filter capacitors of an electric vehicle (EV), to the second core, and to the first core. No signal may be measured by the second core if a resistance of the utility ground is too high or open. A minimum threshold signal measured by the second core may be set to switch off power. In some examples, the minimum threshold signal may be 0.8V, which may correspond to 150-300 ohm ground loop resistance. In other examples, the minimum threshold signal may be set to correspond to a ground loop resistance of 1500 ohm or more.

[0070] The EVSE 3306 may switch between RCD mode and GMI mode in order to test for both conditions. In some examples, the EVSE 3306 may switch to GMI mode four times per second for a maximum duration of 300us. To test for correct operation of the RCD mode prior to closing the relay 3312, the microcontroller 3310 may command a current source for the compensation winding to inject a test current. In other examples, a test button may included that connects a resistor between ground and line using a switch. The response time to cut power may be varied based on the application and any regulatory requirements. The response time may be a function of the leakage current magnitude. Power may be cut on leakage current in 1ms and missing ground in 300us. However, a quicker time to cut power may create unnecessary trips due to noise. While a microcontroller 3310 is depicted in the system 3300, one or all of its functions may be replaced by analog and logic circuitry in some embodiments as disclosed herein. Likewise, additional microcontrollers may be used to accomplish different functions.

[0071] It is intended that the scope of the present invention is herein disclosed by way of examples and should not be limited by the particular disclosed embodiments described above, wherein the claims shall define the matter for which protection is sought.

Claims

1. A transformer (100, 200) comprising:

a first drive winding (112, 206) wound on a first core (102, 202), wherein the transformer (100, 200) is adapted to drive the first drive winding (112, 206) with a first high frequency square wave current (216);
a second drive winding (114, 208) wound on a second core (104, 204), wherein the transformer (100, 200) is adapted to drive the second drive winding (114, 208) with a second high frequency square wave current (216), and wherein the second high frequency square wave current (216) has an opposite polarity of the first high frequency square wave current (216);
a sense winding (110, 210) wound across the first and second cores (102, 104, 202, 204);
a compensation winding (108, 212) wound across the first and second cores (102, 104, 202, 204); and
one or more utility lines (214) that are threaded through a middle of the first and second cores (102, 104, 202, 204), wherein the utility lines (214) are adapted such that a common mode current in the one or more utility lines (214) causes one or more pulses to appear on the sense winding (110, 210), wherein the transformer (100, 200) is adapted to adjust a current on the compensation winding (108, 212) until the one or more pulses on the sense winding (110, 210) are cancelled out, and wherein the common mode current on the one or more utility lines (214) is the adjusted current on the compensation winding (108, 212) multiplied by a turn ratio between the compensation winding (108, 212) and the sense winding (110, 210),
characterized in that
the first core (102, 202) has a lower saturation flux density than the second core (104, 204), and wherein the transformer (100, 200) is configured to drive the first drive winding (112, 206) with less current than the second drive winding

(114, 208) such that the first core (102, 202) saturates at substantially the same time as the second core (104, 204).

2. The transformer (1 00, 200) of claim 1, wherein a net flux through the sense winding (110, 210) is zero if no common mode current is present on the one or more utility lines (214).

3. The transformer (1 00, 200) of claim 1, wherein a saturation flux density of the first core (102, 202) is within 10% of the saturation flux density of the second core (104, 204).

4. The transformer (1 00, 200) of claim 1, wherein the first drive winding (112, 206) is adapted to apply a high frequency signal (216) to the one or more utility lines (214), wherein the transformer (100, 200) is adapted to measure, via the second drive winding (114, 208), an amplitude of a current that results, and wherein the amplitude of the current that results is proportional to a reciprocal of a ground loop impedance.

5. The transformer (1 00, 200) of claim 1, wherein the common mode current in the utility line (214) is at least one of: an AC residual leakage current and a DC residual leakage current.

6. The transformer (1 00, 200) of claim 1, wherein the first core (102, 202) is disposed substantially parallel to the second core (104, 204).

7. A method (3100) comprising:

providing a first high frequency square wave current to a first drive winding wound on a first core (3102);
providing a second high frequency square wave current to a second drive winding wound on a second core (3104), wherein the second high frequency square wave current has an opposite polarity of the first high frequency square wave current;
sensing one or more pulses on a sense winding wound about the first and second cores (3106), wherein the one or more pulses are created by a common mode current on one or more utility lines threaded through the first and second cores;
adjusting a current to a compensation winding wound about the first and second cores to cancel out the one or more pulses on the sense winding (3106);
determining the common mode current on the one or more utility lines as the current on the compensation winding multiplied by a turn ratio between the compensation winding and the sense winding (3108),
characterized in that
the first core has a lower saturation flux density than the second core and wherein the first drive winding is driven with less current than the second drive winding such that the first core saturates at substantially the same time as the second core.

8. The method (3100) of claim 7, wherein a saturation flux density of the first core is within 10% of the saturation flux density of the second core, or
wherein the method (3100, 3200) further comprises:

providing a high frequency signal to the one or more utility lines by the first drive winding (3202); and
measuring an amplitude of a current that results by the second drive winding (3204), wherein the amplitude of the current that results is proportional to a reciprocal of a ground loop impedance, or
wherein the common mode current in the utility line is at least one of: an AC residual leakage current and a DC residual leakage current.

9. The method of claim 8,
wherein the method further comprises:

measuring one or more peaks of a rising edge of the sensed one or more pulses by a first sample and hold circuit;
measuring one or more peaks of a falling edge of the sensed one or more pulses by a second sample and hold circuit;
determining a difference in magnitude between an average of the peaks of the rising edges and an average of the peaks of the falling edges; and
adjusting at least one of: the first high frequency square wave current and the second high frequency square wave current based on the determined difference in magnitude, wherein the adjusted current compensates for a difference in a saturation flux density between the first core and the second core.

10. The method of claim 8, wherein a high frequency signal is provided to the one or more utility lines by the first drive winding and wherein an amplitude of a current that results by the second drive winding is measured, wherein the amplitude of the current that results is proportional to a reciprocal of a ground loop impedance, wherein the high frequency signal driven by the first drive winding flows to a utility ground, to an electric vehicle service equipment (EVSE) through a ground wire, to ground filter capacitors of the EVSE and to ground filter capacitors of an electric vehicle (EV), to the second core, and to the first core,

preferably, wherein no signal is measured by the second core if a resistance of the utility ground is too high or open.

Patentansprüche

1. Transformator (100, 200), umfassend:

eine erste Treiberwicklung (112, 206), welche auf einen ersten Kern (102, 202) gewickelt ist, wobei der Transformator (100, 200) dazu eingerichtet ist, die erste Treiberwicklung (112, 206) mit einem ersten Hochfrequenzrechteckwellenstrom (216) zu erregen;
eine zweite Treiberwicklung (114, 208), welche auf einen zweiten Kern (104, 204) gewickelt ist, wobei der Transformator (100, 200) dazu eingerichtet ist, die zweite Treiberwicklung (114, 208) mit einem zweiten Hochfrequenzrechteckwellenstrom (216) zu erregen und wobei der zweite Hochfrequenzrechteckwellenstrom (216) eine dem ersten Hochfrequenzrechteckwellenstrom (216) entgegengesetzte Polarität aufweist;
eine Abtastwicklung (110, 210), welche um den ersten und zweiten Kern (102, 104, 202, 204) gewickelt ist;
eine Kompensationswicklung (108, 212), welche um den ersten und zweiten Kern (102, 104, 202, 204) gewickelt ist; und
eine oder mehrere Versorgungsleitungen (214), welche durch eine Mitte des ersten und zweiten Kerns (102, 104, 202, 204) geführt sind, wobei die Versorgungsleitungen (214) derart eingerichtet sind, dass ein Gleichtaktstrom in der einen oder den mehreren Versorgungsleitungen (214) ein Auftreten von einem oder mehreren Impulsen in der Abtastwicklung (110, 210) bewirkt, wobei der Transformator (100, 200) dazu eingerichtet ist, einen Strom in der Kompensationswicklung (108, 212) anzupassen bis der eine oder die mehreren Impulse in der Abtastwicklung (110, 210) aufgehoben werden und wobei der Gleichtaktstrom in der einen oder den mehreren Versorgungsleitungen (214) der angepasste Strom in der Kompensationswicklung (108, 212) multipliziert mit einem Wicklungsverhältnis zwischen der Kompensationswicklung (108, 212) und der Abtastwicklung (110, 210) ist,
dadurch gekennzeichnet, dass
der erste Kern (102, 202) eine niedrigere Sättigungsflussdichte aufweist als der zweite Kern (104, 204), wobei der Transformator (100, 200) dazu konfiguriert ist, die erste Treiberwicklung (112, 206) mit weniger Strom zu erregen als die zweite Treiberwicklung (114, 208), sodass der erste Kern (102, 202) in der im Wesentlichen gleichen Zeit gesättigt wird wie der zweite Kern (104, 204).

2. Transformator (100, 200) nach Anspruch 1, wobei ein Nettofluss durch die Abtastwicklung (110, 210) null ist, wenn kein Gleichtaktstrom in der einen oder den mehreren Versorgungsleitungen (214) vorhanden ist.

3. Transformator (100, 200) nach Anspruch 1, wobei eine Sättigungsflussdichte des ersten Kerns (102, 202) innerhalb von 10 % der Sättigungsflussdichte des zweiten Kerns (104, 204) liegt.

4. Transformator (100, 200) nach Anspruch 1, wobei die erste Treiberwicklung (112, 206) dazu eingerichtet ist, ein Hochfrequenzsignal (216) an die eine oder mehreren Versorgungsleitungen (214) anzulegen, wobei der Transformator (100, 200) dazu eingerichtet ist, über die zweite Treiberwicklung (114, 208) eine Amplitude eines resultierenden Stroms zu messen, wobei die Amplitude des resultierenden Stroms proportional zu einem Reziprokwert einer Erdschleifenimpedanz ist.

5. Transformator (100, 200) nach Anspruch 1, wobei der Gleichtaktstrom in der Versorgungsleitung (214) zumindest einer von einem Wechselspannungsfehlerkriechstrom und einem Gleichspannungsfehlerkriechstrom ist.

6. Transformator (100, 200) nach Anspruch 1, wobei der erste Kern (102, 202) im Wesentlichen parallel zu dem zweiten Kern (104, 204) angeordnet ist.

7. Verfahren (3100), umfassend:

Bereitstellen eines ersten Hochfrequenzrechteckwellenstroms für eine erste Treiberwicklung, welche auf einen ersten Kern (3102) gewickelt ist;
Bereitstellen eines zweiten Hochfrequenzrechteckwellenstroms für eine zweite Treiberwicklung, welche auf einen zweiten Kern (3104) gewickelt ist, wobei der zweite Hochfrequenzrechteckwellenstrom eine dem ersten Hochfrequenzrechteckwellenstrom entgegengesetzte Polarität aufweist;
Abtasten eines oder mehrerer Impulse in einer Abtastwicklung, welche um den ersten und zweiten Kern (3106) gewickelt ist, wobei der eine oder die mehreren Impulse durch einen Gleichtaktstrom in einer oder mehreren Versorgungsleitungen erzeugt werden, welche durch den ersten und zweiten Kern geführt sind;
Anpassen eines Stroms an eine Kompensationswicklung, welche um den ersten und zweiten Kern gewickelt ist, um den einen oder die meh-

reren Impulse in der Abtastwicklung (3106) aufzuheben;

Bestimmen des Gleichtaktstroms in der einen oder den mehreren Versorgungsleitungen als den Strom in der Kompensationswicklung multipliziert mit einem Wicklungsverhältnis zwischen der Kompensationswicklung und der Abtastwicklung (3108),

dadurch gekennzeichnet, dass

der erste Kern eine niedrigere Sättigungsflussdichte aufweist als der zweite Kern, wobei die erste Treiberwicklung mit weniger Strom erregt wird als die zweite Treiberwicklung, sodass der erste Kern in der im Wesentlichen gleichen Zeit gesättigt wird wie der zweite Kern.

8. Verfahren (3100) nach Anspruch 7, wobei eine Sättigungsflussdichte des ersten Kerns innerhalb von 10 % der Sättigungsflussdichte des zweiten Kerns liegt, oder
wobei das Verfahren (3100, 3200) weiter umfasst:

Bereitstellen eines Hochfrequenzsignals für die eine oder mehreren Versorgungsleitungen durch die erste Treiberwicklung (3202); und

Messen einer Amplitude eines resultierenden Stroms durch die zweite Treiberwicklung (3204), wobei die Amplitude des resultierenden Stroms proportional zu einem Reziprokwert einer Erdschleifenimpedanz ist, oder

wobei der Gleichtaktstrom in der Versorgungsleitung zumindest einer von einem Wechselspannungsfehlerkriechstrom und einem Gleichspannungsfehlerkriechstrom ist.

9. Verfahren nach Anspruch 8,
wobei das Verfahren weiter umfasst:

Messen einer oder mehrerer Spitzen einer steigenden Flanke der abgetasteten einen oder mehreren Impulse durch eine erste Abtast-Halte-Schaltung;

Messen einer oder mehrerer Spitzen einer fallenden Flanke der abgetasteten einen oder mehreren Impulse durch eine zweite Abtast-Halte-Schaltung;

Bestimmen einer Differenz in der Größenordnung zwischen einem Mittelwert der Spitzen der steigenden Flanken und einem Mittelwert der Spitzen der fallenden Flanken; und

Anpassen zumindest eines von dem ersten Hochfrequenzrechteckwellenstrom und dem zweiten Hochfrequenzrechteckwellenstrom auf Basis der bestimmten Differenz in der Größenordnung, wobei der angepasste Strom eine Differenz in einer Sättigungsflussdichte zwischen dem ersten Kern und dem zweiten Kern ausgleicht.

10. Verfahren nach Anspruch 8, wobei ein Hochfrequenzsignal für die eine oder mehreren Versorgungsleitungen durch die erste Treiberwicklung bereitgestellt wird und wobei eine Amplitude eines resultierenden Stroms durch die zweite Treiberwicklung gemessen wird, wobei die Amplitude des resultierenden Stroms proportional zu einem Reziprokwert einer Erdschleifenimpedanz ist, wobei das durch die erste Treiberwicklung erregte Hochfrequenzsignal zu einer Versorgungserdung, zu einem Electric Vehicle Supply Equipment (EVSE) durch eine Erdungsleitung, zu Erdungsfilterkondensatoren der EVSE und zu Erdungsfilterkondensatoren eines Elektrofahrzeugs (EV), zu dem zweiten Kern, und zu dem ersten Kern fließt, wobei bevorzugt durch den zweiten Kern kein Signal gemessen wird, wenn ein Widerstand der Versorgungserdung zu hoch oder offen ist.

Revendications

1. Transformateur (100, 200) comprenant :

un premier enroulement de commande (112, 206) enroulé sur un premier noyau (102, 202), dans lequel le transformateur (100, 2c00) est adapté pour commander le premier enroulement de commande (112, 206) avec un premier courant à ondes carrées haute fréquence (216) ;

un second enroulement de commande (114, 208) enroulé sur un second noyau (104, 204), dans lequel le transformateur (100, 200) est adapté pour commander le second enroulement de commande (114, 208) avec un second courant à ondes carrées haute fréquence (216), et dans lequel le second courant à ondes carrées haute fréquence (216) présente une polarité opposée au premier courant à ondes carrées haute fréquence (216) ;

un enroulement de détection (110, 210) enroulé sur les premier et second noyaux (102, 104, 202, 204) ;

un enroulement de compensation (108, 212) enroulé sur les premier et second noyaux (102, 104, 202, 204) ; et

un ou plusieurs câbles de service public (214) qui sont introduits au milieu des premier et second noyaux (102, 104, 202, 204), dans lequel les câbles de service public (214) sont adaptés de sorte qu'un courant de mode commun dans les un ou plusieurs câbles de service public (214) amène une ou plusieurs impulsions à apparaître sur l'enroulement de détection (110, 210), dans lequel le transformateur (100, 200) est adapté pour ajuster un courant sur l'enroulement de compensation (108, 212) jusqu'à ce que les une ou plusieurs impulsions sur l'enroulement de détection (110, 210) soient annulées, et dans lequel le courant de mode commun sur les un ou plusieurs câbles de service public (214) est le courant ajusté sur l'enroulement de compensation (108, 212) multiplié par un rapport de transformation entre l'enroulement de compensation (108, 212) et l'enroulement de détection (110, 210),

caractérisé en ce que

le premier noyau (102, 202) présente une plus faible densité de flux de saturation que le second noyau (104, 204), et dans lequel le transformateur (100, 200) est configuré pour commander le premier enroulement de commande (112, 206) avec moins de courant que le second enroulement de commande (114, 208) de sorte que le premier noyau (102, 202) sature sensiblement en même temps que le second noyau (104, 204).

2. Transformateur (100, 200) selon la revendication 1, dans lequel un flux net à travers l'enroulement de détection (110, 210) est nul si aucun courant de mode commun n'est présent sur les un ou plusieurs câbles de service public (214).

3. Transformateur (100, 200) selon la revendication 1, dans lequel une densité de flux de saturation du premier noyau (102, 202) est dans les 10 % de la densité de flux de saturation du second noyau (104, 204).

4. Transformateur (100, 200) selon la revendication 1, dans lequel le premier enroulement de commande (112, 206) est adapté pour appliquer un signal haute fréquence (216) sur les un ou plusieurs câbles de service public (214), dans lequel le transformateur (100, 200) est adapté pour mesurer, via le second enroulement de commande (114, 208), une amplitude d'un courant qui résulte, et dans lequel l'amplitude du courant qui résulte est proportionnelle à une réciproque d'une impédance de boucle de masse.

5. Transformateur (100, 200) selon la revendication 1, dans lequel le courant de mode commun dans le câble de service public (214) est au moins un de : un courant de fuite résiduel c.a. et un courant de fuite résiduel c.c.

6. Transformateur (100, 200) selon la revendication 1, dans lequel le premier noyau (102, 202) est disposé sensiblement parallèlement au second noyau (104, 204).

7. Procédé (3100) comprenant :

une fourniture d'un premier courant à ondes carrées haute fréquence à un premier enroulement de commande enroulé sur un premier noyau (3102) ;

une fourniture d'un second courant à ondes carrées haute fréquence à un second enroulement de commande sur un second noyau (3104), dans lequel le second courant à ondes carrées haute fréquence présente une polarité opposée au premier courant à ondes carrées haute fréquence ;

une détection d'une ou plusieurs impulsions sur un enroulement de détection enroulé autour des premier et second noyaux (3106), dans lequel les une ou plusieurs impulsions sont créées par un courant de mode commun sur un ou plusieurs câbles de service public introduits à travers les premier et second noyaux ;

un ajustement d'un courant sur un enroulement de compensation enroulé autour des premier et second noyaux pour annuler les une ou plusieurs impulsions sur l'enroulement de détection (3106) ;

une détermination du courant de mode commun sur les un ou plusieurs câbles de service public comme étant le courant sur l'enroulement de compensation multiplié par un rapport de transformation entre l'enroulement de compensation et l'enroulement de détection (3108),

caractérisé en ce que

le premier noyau présente une plus faible densité de flux de saturation que le second noyau et dans lequel le premier enroulement de commande est commandé avec moins de courant que le second enroulement de commande de sorte que le premier noyau sature sensiblement en même temps que le second noyau.

8. Procédé (3100) selon la revendication 7, dans lequel une densité de flux de saturation du premier noyau est dans les 10 % de la densité de flux de saturation du second noyau, ou

dans lequel le procédé (3100, 3200) comprend en outre :

une fourniture d'un signal haute fréquence aux un ou plusieurs câbles de service public par le premier enroulement de commande (3202) ; et une mesure d'une amplitude d'un courant qui résulte par le second enroulement de commande (3204), dans lequel l'amplitude du courant qui résulte est proportionnelle à une réciproque d'une impédance de boucle de masse, ou

dans lequel le courant de mode commun dans le câble de service public est au moins un de : un courant de fuite résiduel c.a. et un courant de fuite résiduel c.c.

9. Procédé selon la revendication 8,

dans lequel le procédé comprend en outre :

une mesure d'un ou plusieurs pics d'un front montant des une ou plusieurs impulsions détectées par un premier échantillonneur-bloqueur ;
une mesure d'un ou plusieurs pics d'un front descendant des une ou plusieurs impulsions détectées par un second échantillonneur-bloqueur ;
une détermination d'une différence de magnitude entre une moyenne des pics des fronts montants et une moyenne des pics des fronts descendants ; et
un ajustement d'au moins un de : le premier courant à ondes carrées haute fréquence et le second courant à ondes carrées haute fréquence sur la base de la différence de magnitude déterminée, dans lequel le courant ajusté compense une différence de densité de flux de saturation entre le premier noyau et le second noyau.

10. Procédé selon la revendication 8, dans lequel un signal haute fréquence est fourni aux un ou plusieurs câbles de service public par le premier enroulement de commande et dans lequel une amplitude d'un courant qui résulte par le second enroulement de commande est mesurée, dans lequel l'amplitude du courant qui résulte est proportionnelle à une réciproque d'une impédance de boucle de masse, dans lequel le signal haute fréquence commandé par le premier enroulement de commande circule vers une masse de service public, vers un équipement de service de véhicule électrique (EVSE) à travers un fil de masse, pour mettre à la masse des condensateurs de filtrage de l'EVSE et pour mettre à la masse des condensateurs de filtrage d'un véhicule électrique (EV), vers le second noyau, et vers le premier noyau, de préférence, dans lequel aucun signal n'est mesuré par le second noyau si une résistance de la masse de service public est trop élevée ou ouverte.

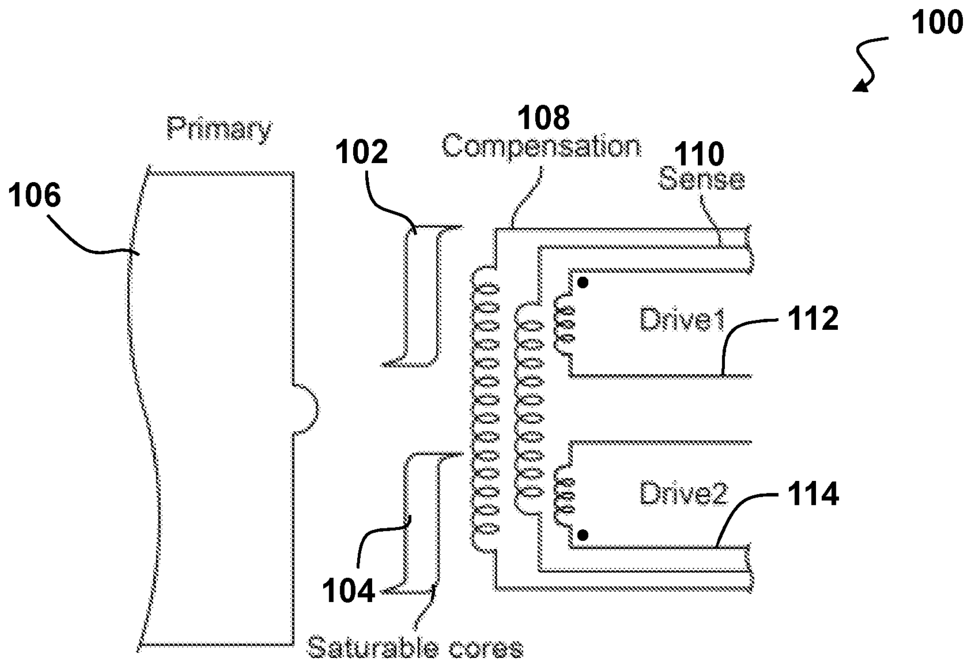


FIG. 1

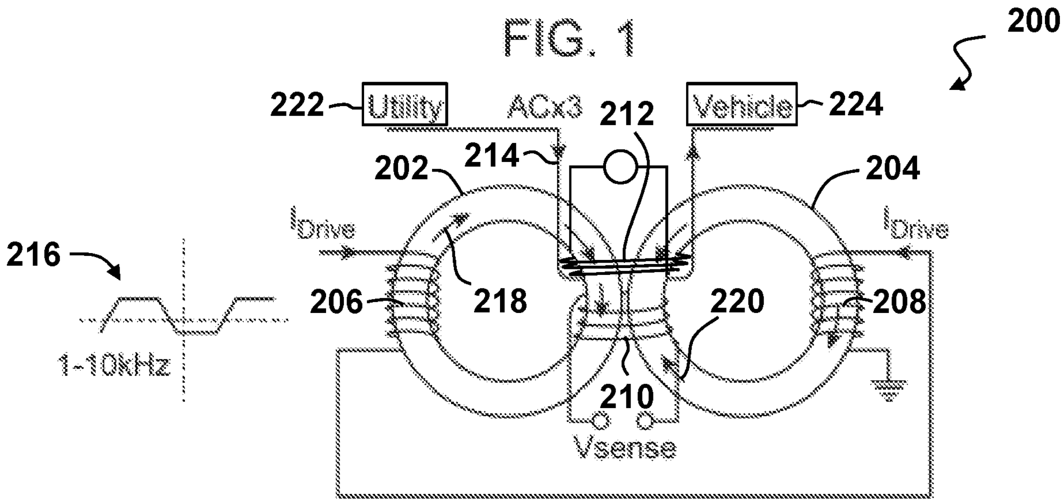


FIG. 2

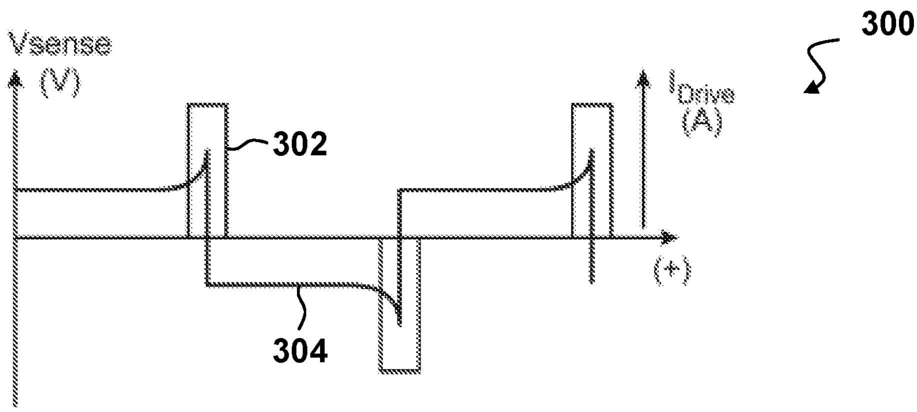


FIG. 3

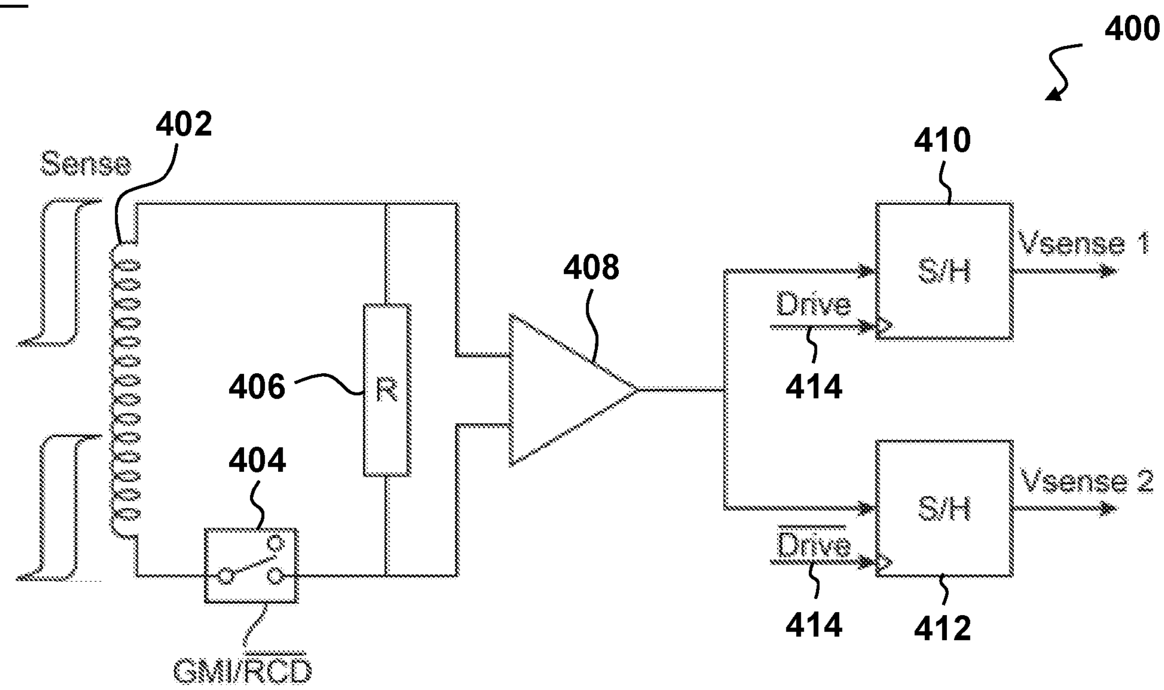

400
402
Sense
410
408
S/H
Vsense 1
Drive
406
R
414
404
S/H
Vsense 2
Drive
414
412
GMI/RCD

FIG. 4

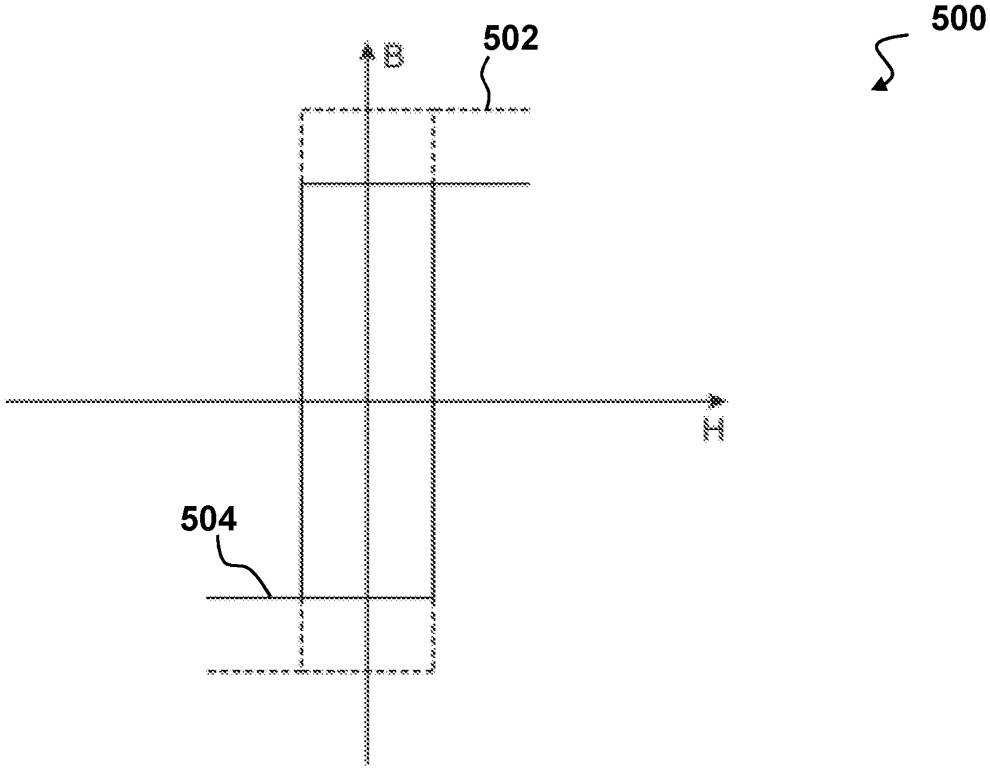

500
B
502
H
504

FIG. 5

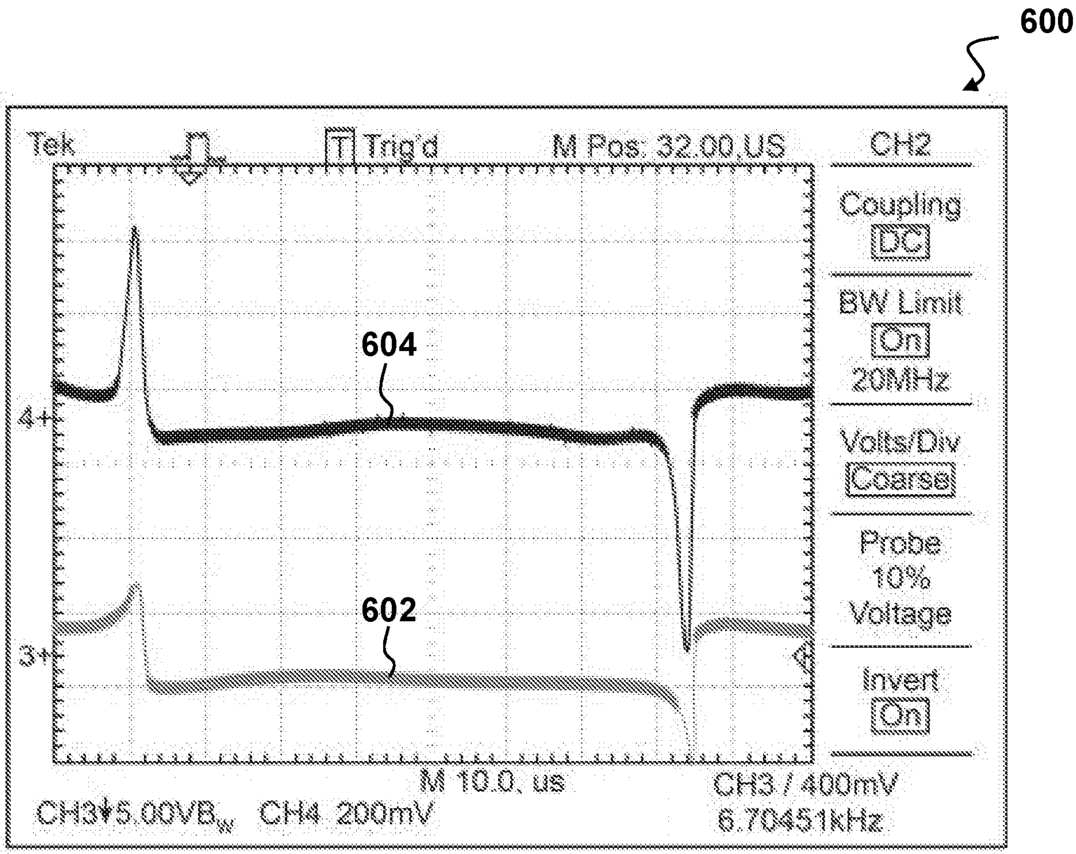

600
Tek
Trig'd
M Pos: 32.00 US
CH2
Coupling
DC
BW Limit
On
20MHz
Volts/Div
Coarse
Probe
10%
Voltage
Invert
On
604
602
4+
3+
M 10.0. us
CH3 / 400mV
6.70451kHz
CH3 5.00VBw CH4 200mV

FIG. 6

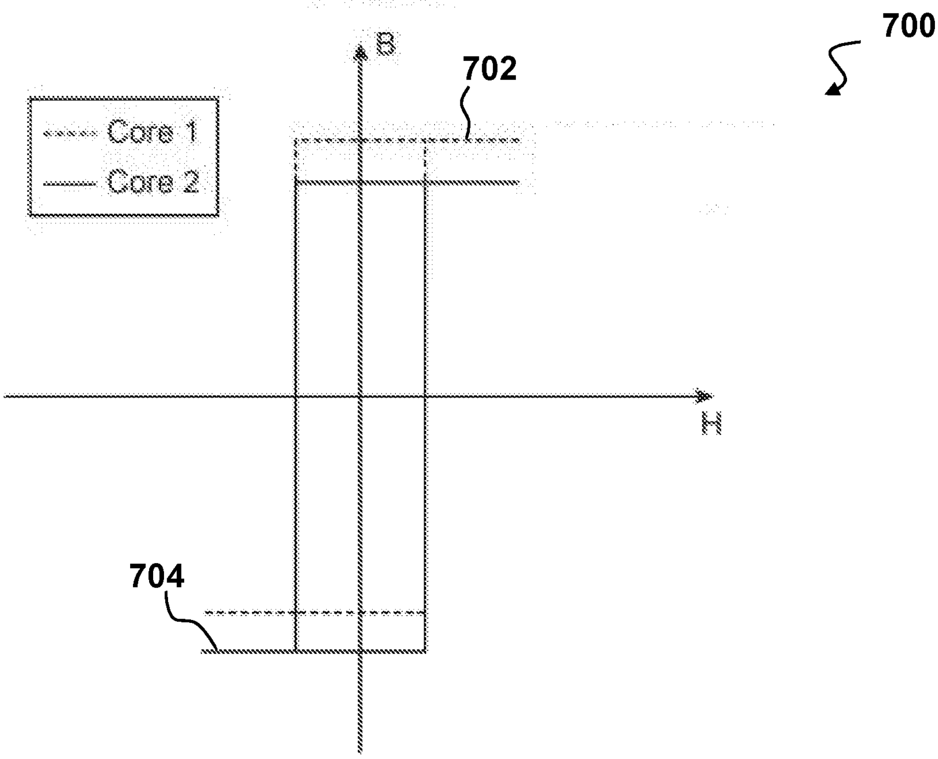

700
B
702
Core 1
Core 2
H
704

FIG. 7

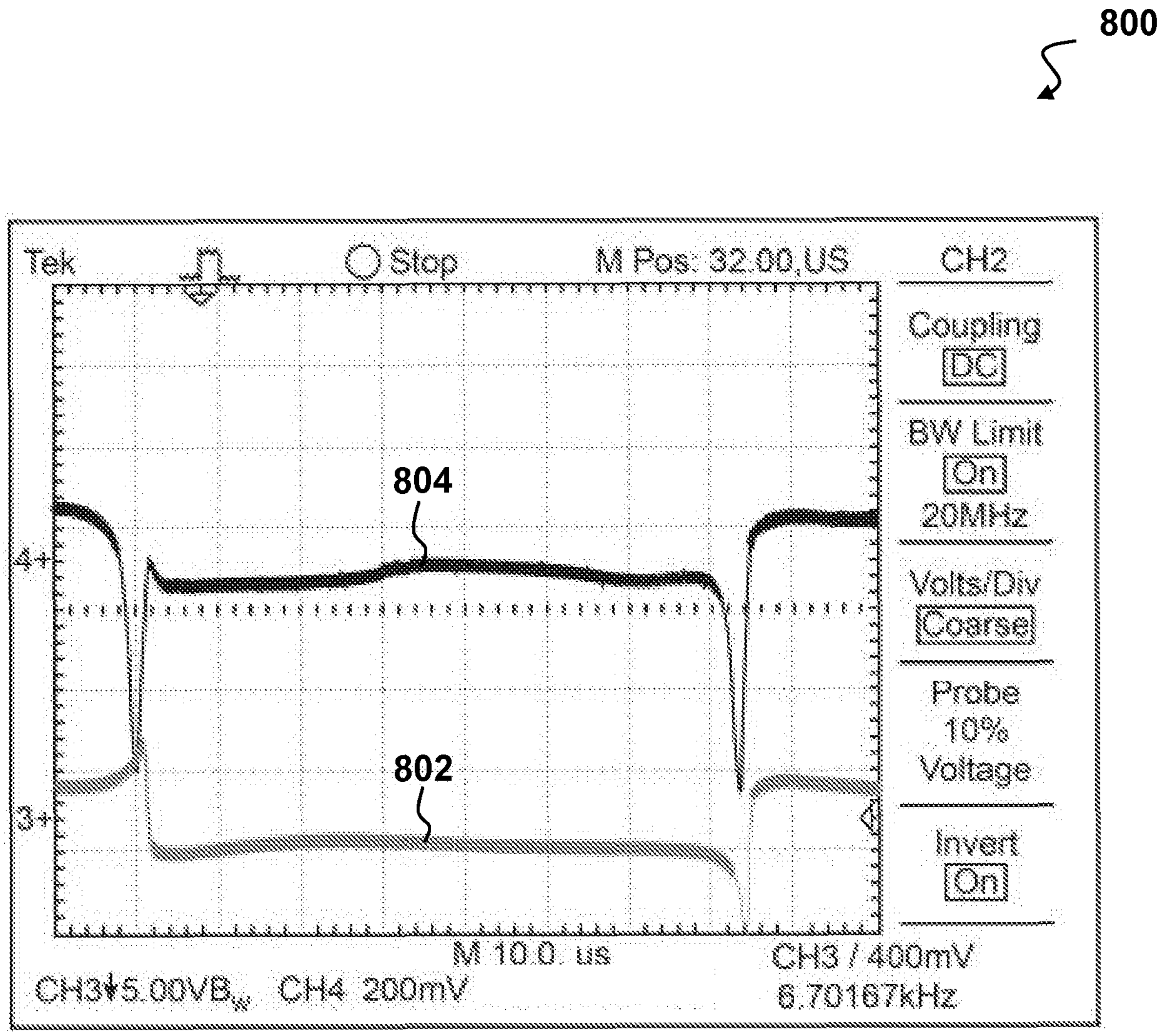

800
Tek
Stop
M Pos: 32.00,US
CH2
Coupling
DC
BW Limit
On
20MHz
Volts/Div
Coarse
Probe
10%
Voltage
Invert
On
804
802
4
3
M 10.0 us
CH3 / 400mV
6.70167kHz
CH3 5.00VB
CH4 200mV

FIG. 8

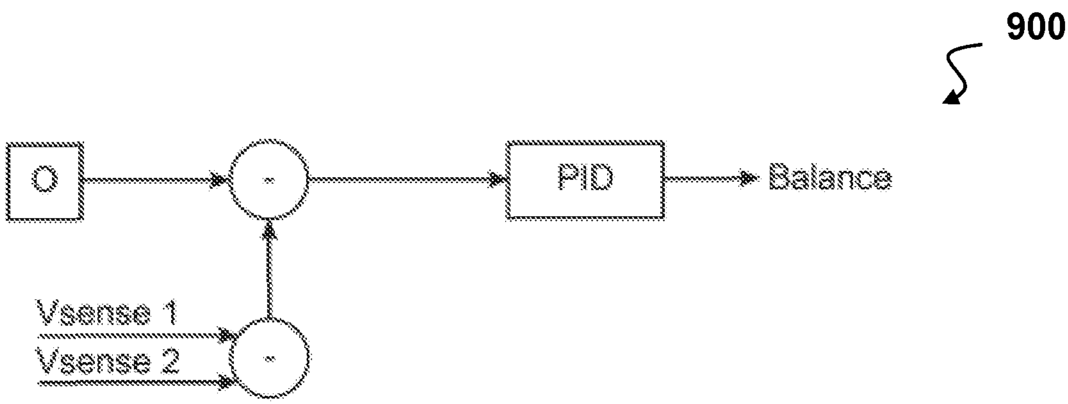
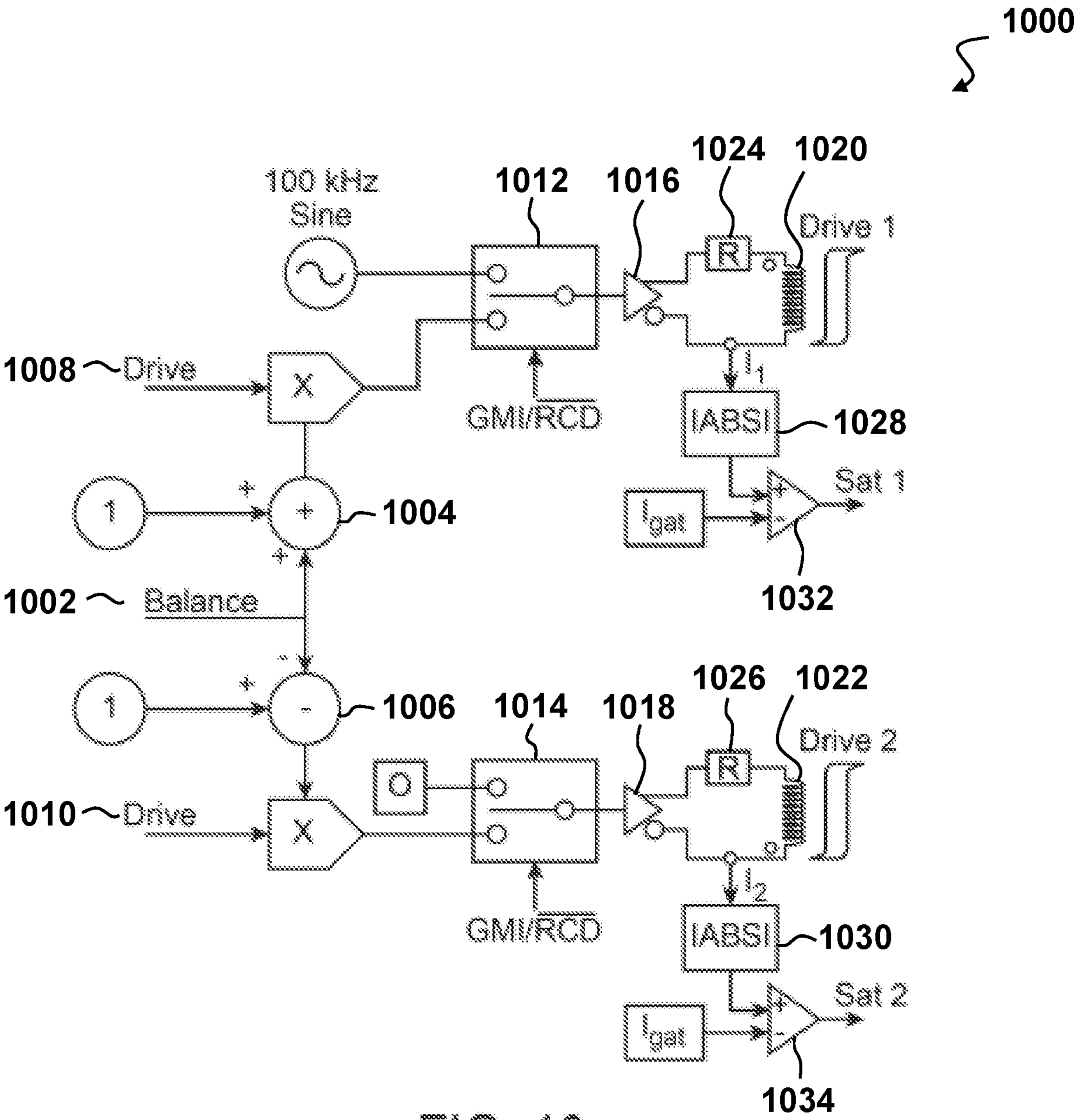
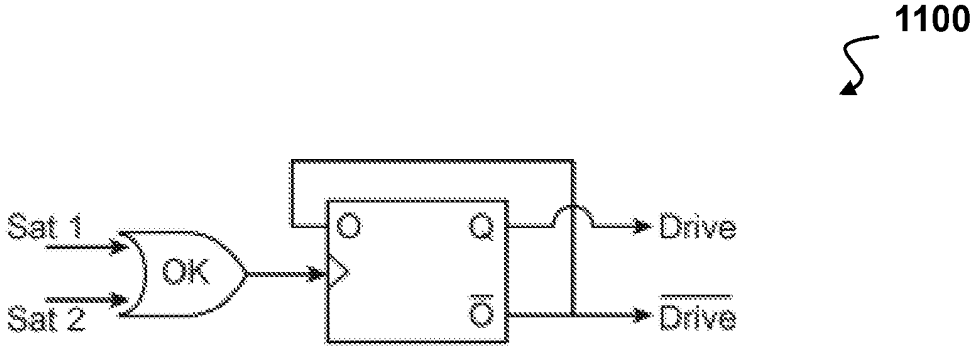

900
O
-
PID
Balance
Vsense 1
Vsense 2
-

FIG. 9



1000
100 kHz
Sine
1012
1016
1024
1020
Drive 1
R
1008
Drive
X
GMI/RCD
IABSI
1028
1
+
1004
Sat 1
Igat
1032
1002
Balance
1
-
1006
1014
1018
1026
1022
Drive 2
0
R
1010
Drive
X
GMI/RCD
IABSI
1030
Sat 2
Igat
1034

FIG. 10



1100
Sat 1
Sat 2
OK
O
Q
Q̄
Drive
Drive

FIG. 11

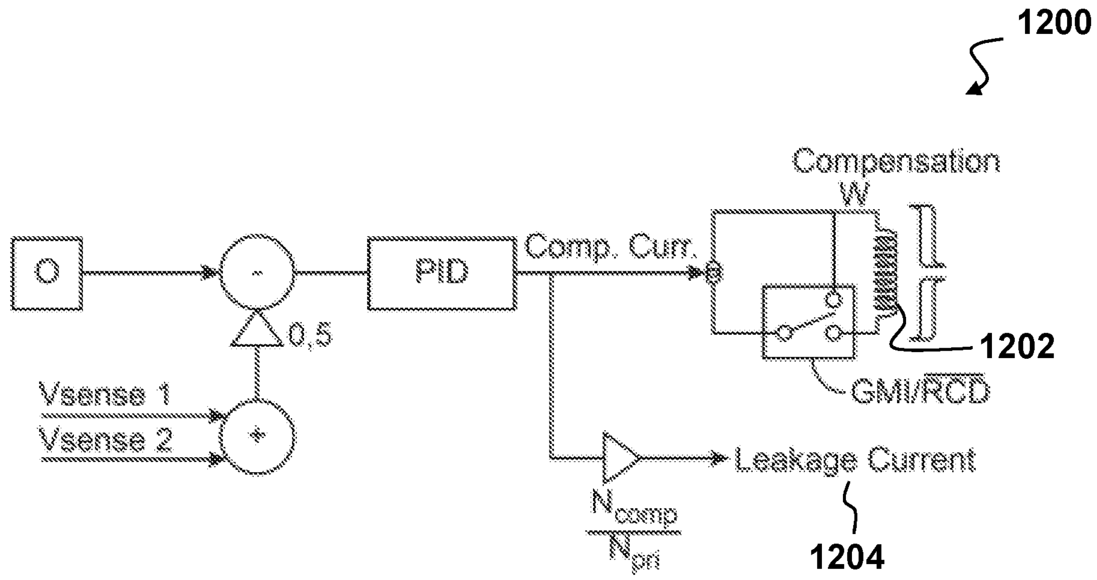


FIG. 12

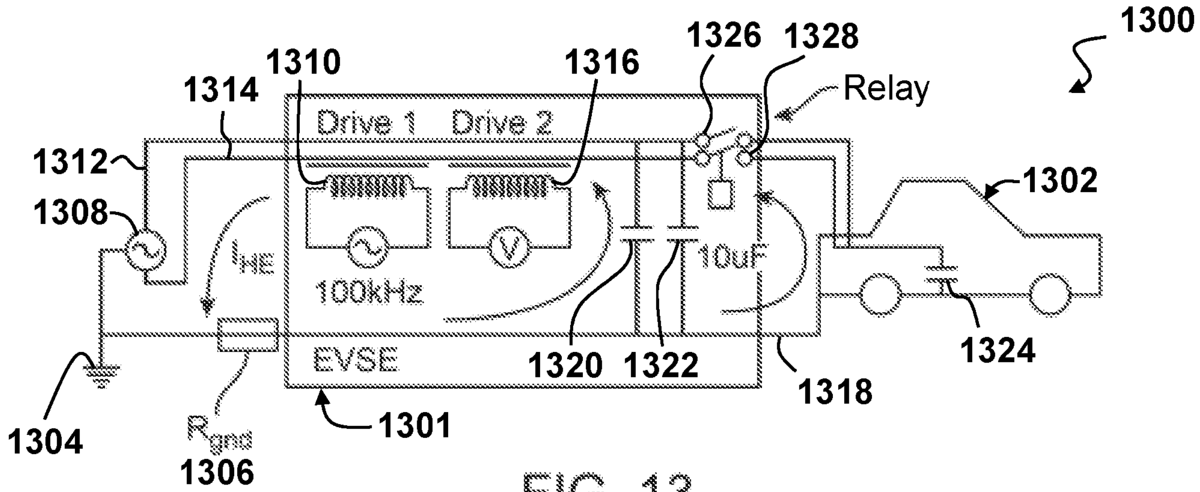


FIG. 13

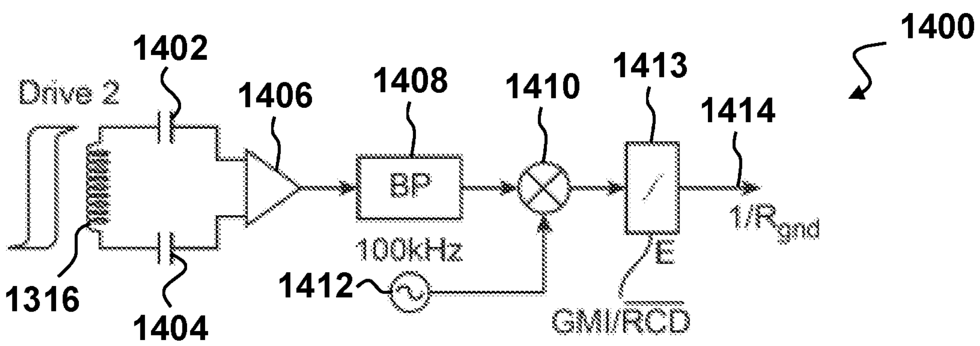


FIG. 14

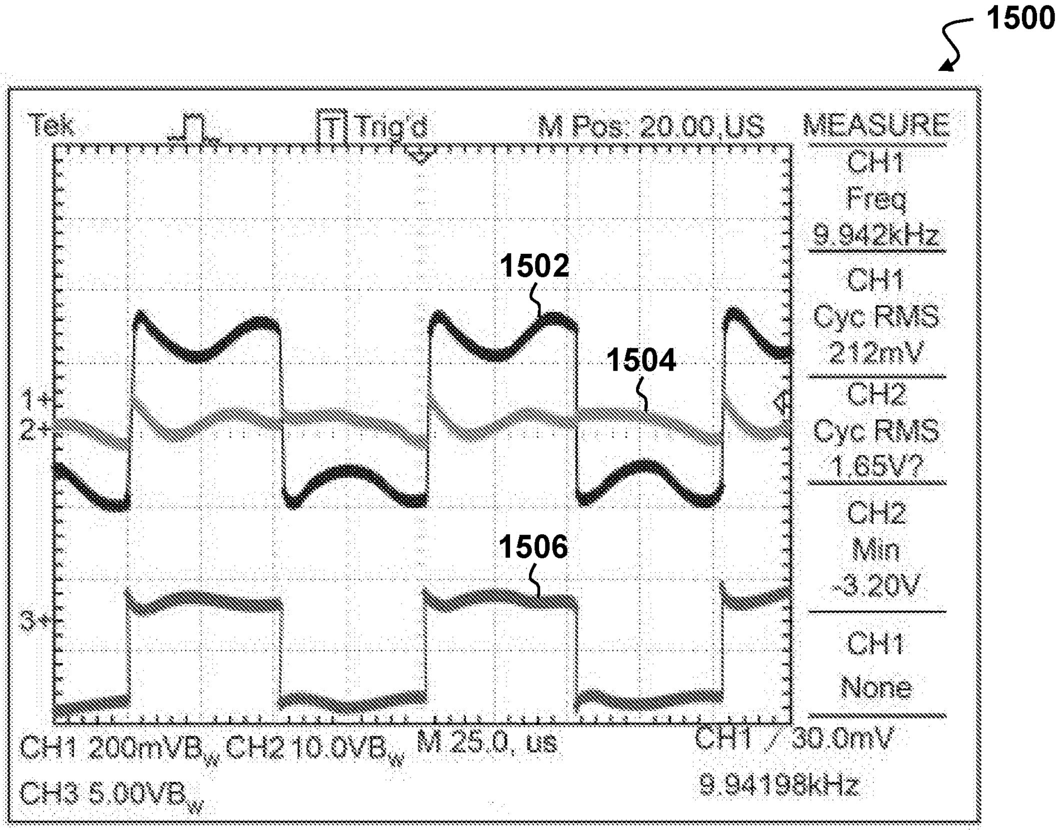

1500
Tek
Trig'd
M Pos: 20.00,US
MEASURE
CH1
Freq
9.942kHz
CH1
Cyc RMS
212mV
CH2
Cyc RMS
1.65V?
CH2
Min
-3.20V
CH1
None
1502
1504
1506
CH1 200mVB$_W$ CH2 10.0VB$_W$ M 25.0, us
CH1 / 30.0mV
CH3 5.00VB$_W$
9.94198kHz

FIG. 15

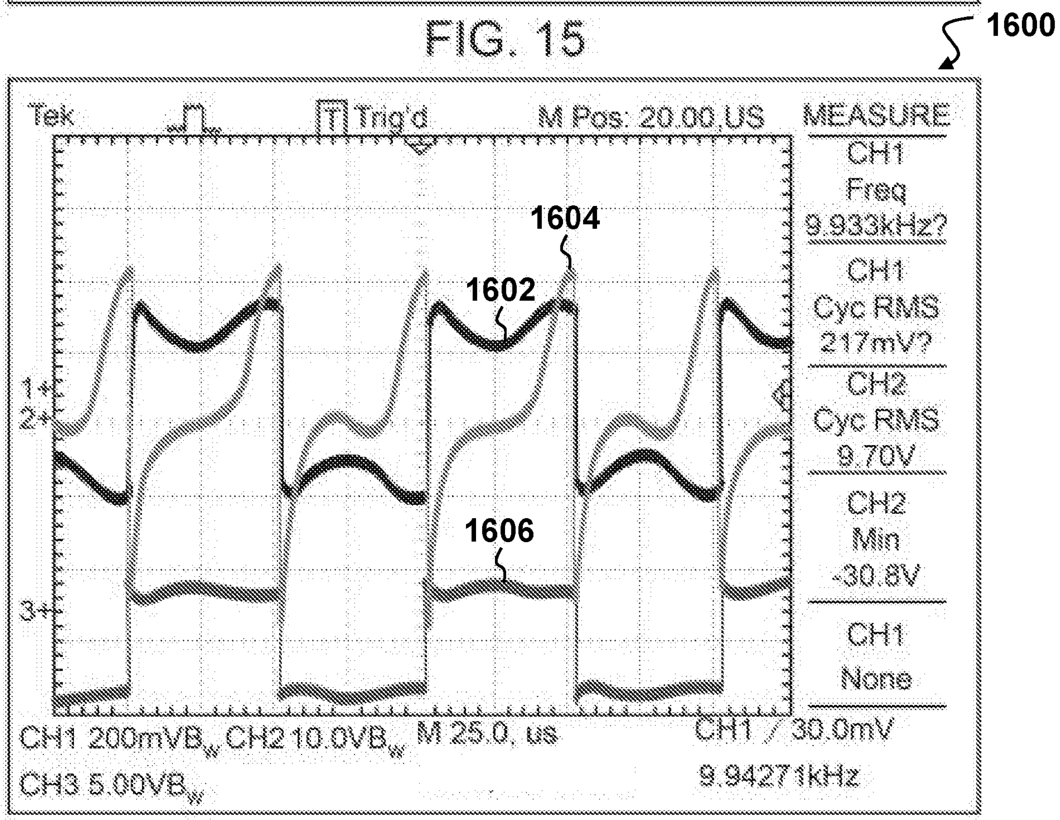

1600
Tek
Trig'd
M Pos: 20.00,US
MEASURE
CH1
Freq
9.933kHz?
CH1
Cyc RMS
217mV?
CH2
Cyc RMS
9.70V
CH2
Min
-30.8V
CH1
None
1602
1604
1606
CH1 200mVB$_W$ CH2 10.0VB$_W$ M 25.0, us
CH1 / 30.0mV
CH3 5.00VB$_W$
9.94271kHz

FIG. 16

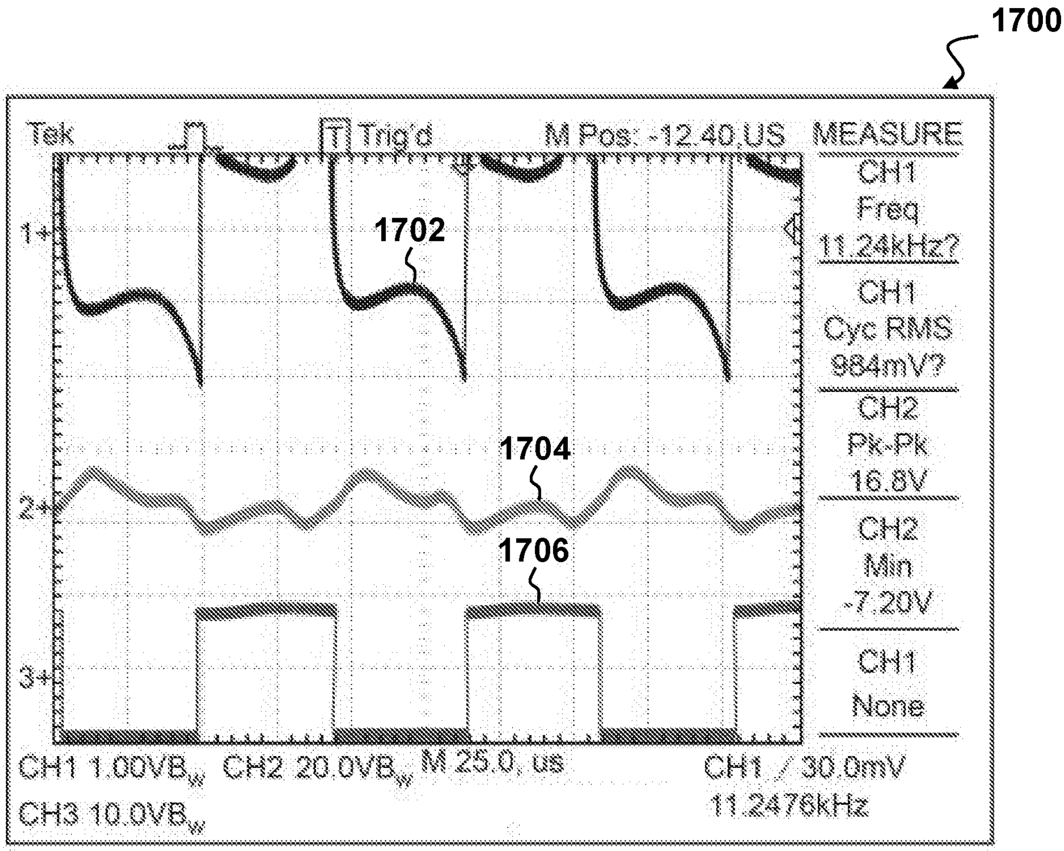

1700
Tek
Trig'd
M Pos: -12.40,US
MEASURE
CH1
Freq
11.24kHz?
CH1
Cyc RMS
984mV?
CH2
Pk-Pk
16.8V
CH2
Min
-7.20V
CH1
None
1702
1704
1706
1+
2+
3+
CH1 1.00VB
CH2 20.0VB
M 25.0, us
CH1 / 30.0mV
CH3 10.0VB
11.2476kHz

FIG. 17

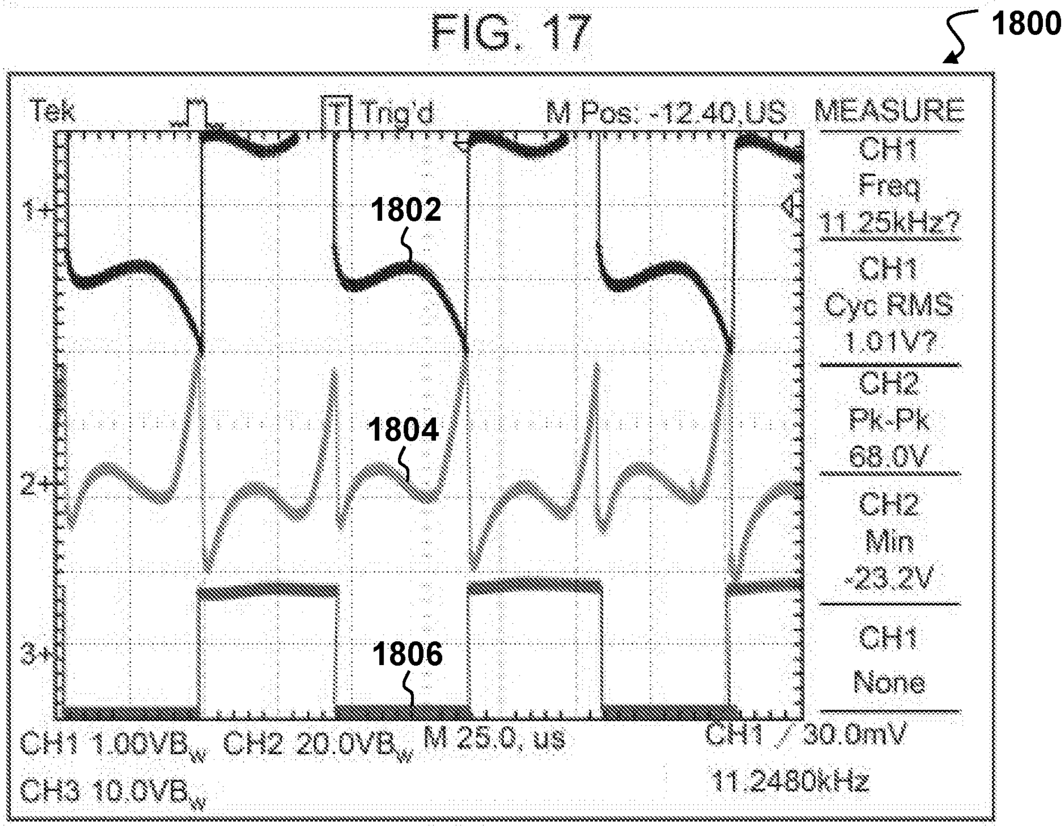

1800
Tek
Trig'd
M Pos: -12.40,US
MEASURE
CH1
Freq
11.25kHz?
CH1
Cyc RMS
1.01V?
CH2
Pk-Pk
68.0V
CH2
Min
-23.2V
CH1
None
1802
1804
1806
1+
2+
3+
CH1 1.00VB
CH2 20.0VB
M 25.0, us
CH1 / 30.0mV
CH3 10.0VB
11.2480kHz

FIG. 18

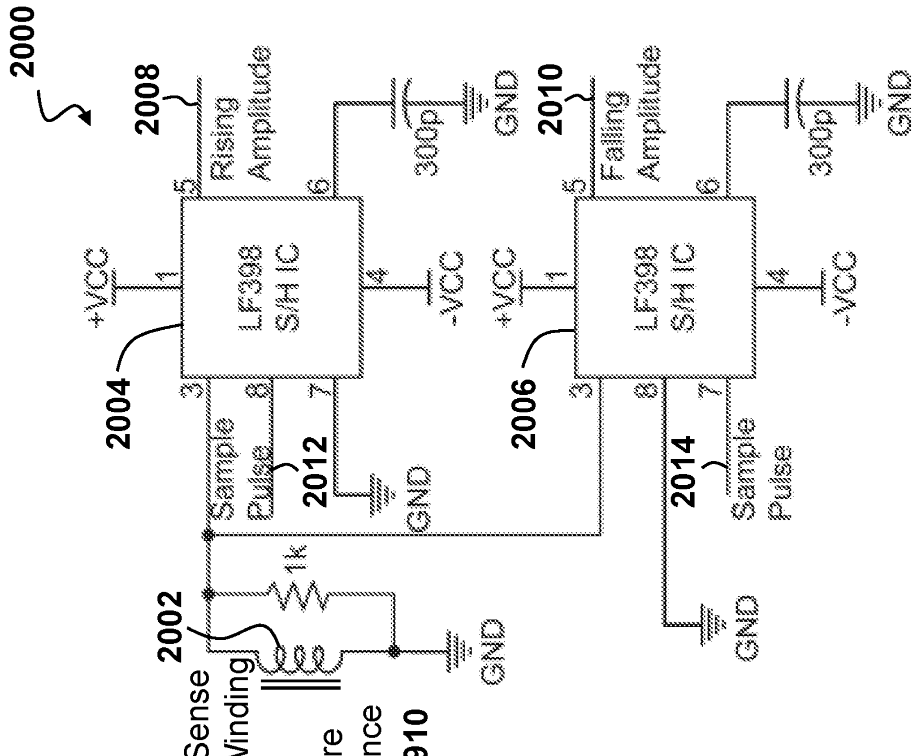

2000
2008
Rising Amplitude
2010
Falling Amplitude
2004
2006
LF398 S/H IC
+VCC
-VCC
300p
GND
Sample Pulse
2012
2014
1k
2002
Sense Winding

FIG. 20

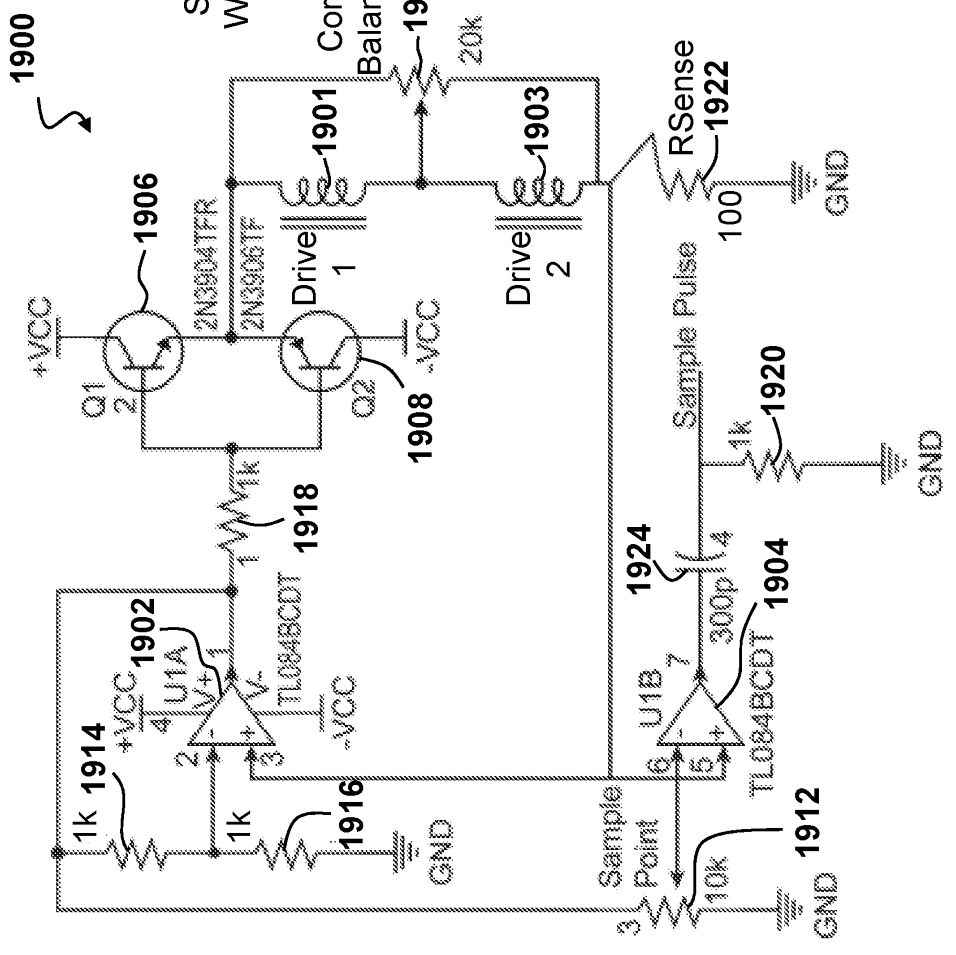

1900
1906
2N3904TFR
2N3906TF
Q1
Q2
1908
+VCC
-VCC
Drive 1
Drive 2
1901
1903
Core Balance
1910
20k
RSense
1922
100
GND
1918
1k
1902
U1A
TL084BCDT
1914
1916
Sample Pulse
1920
1924
300p
1904
U1B
Sample Point
1912
10k

FIG. 19

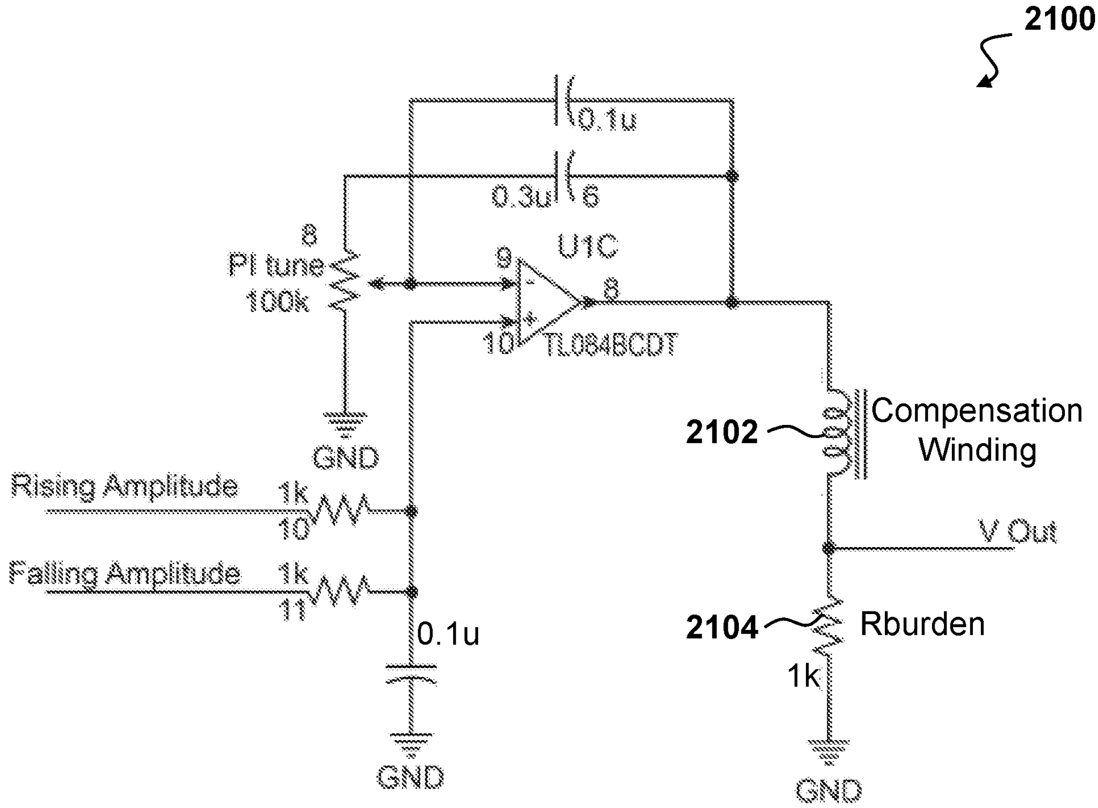


FIG. 21

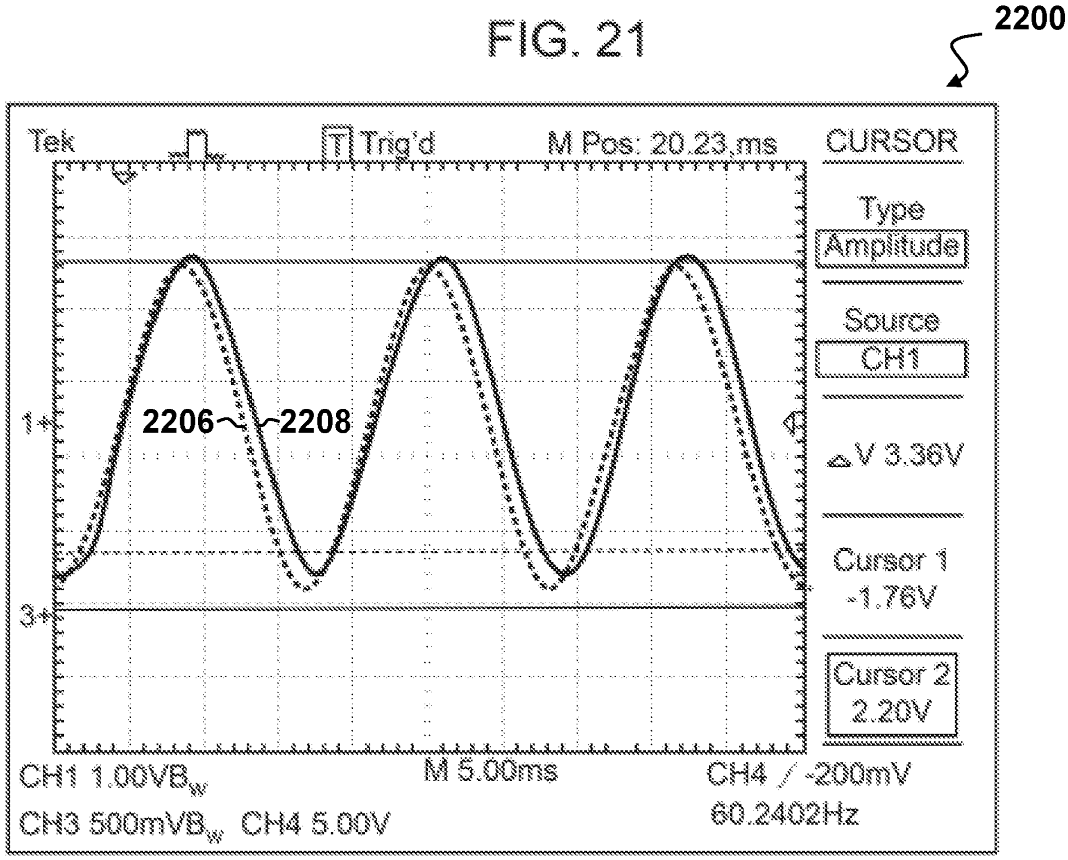


FIG. 22A

2202

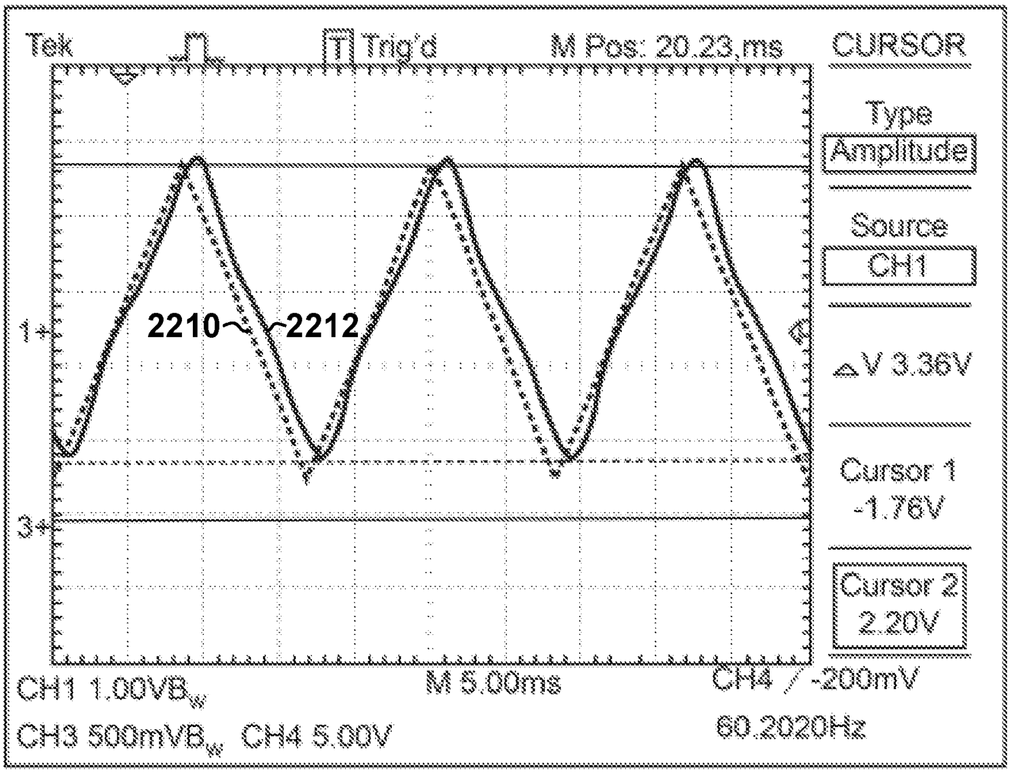


FIG. 22B

2204

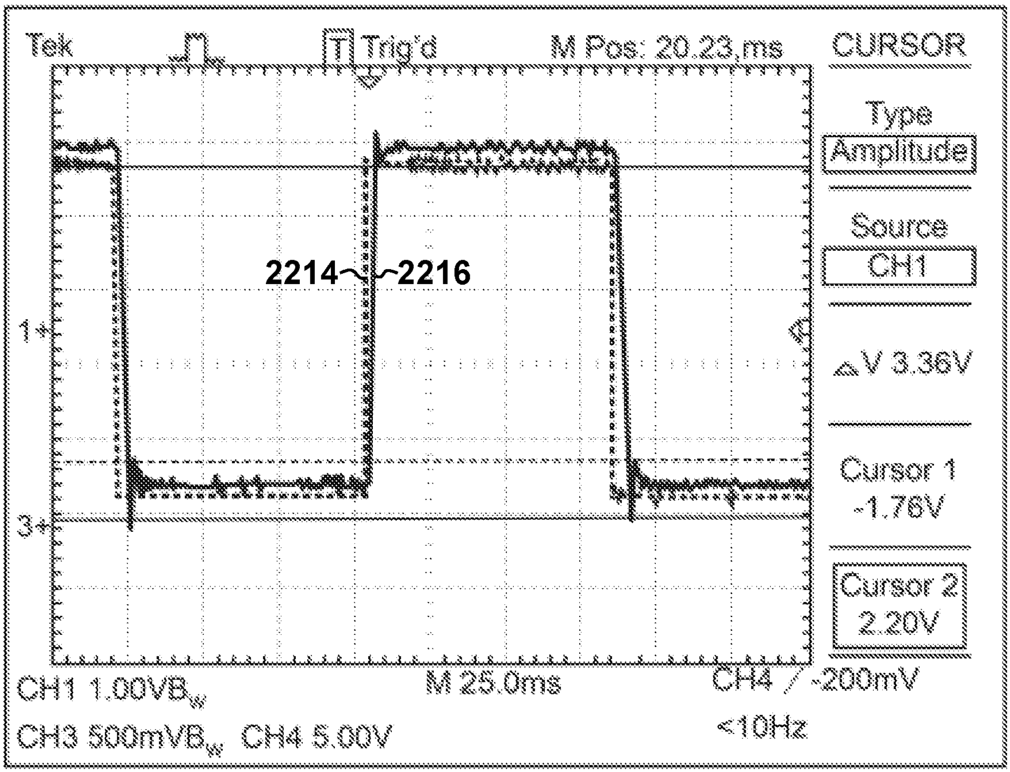


FIG. 22C

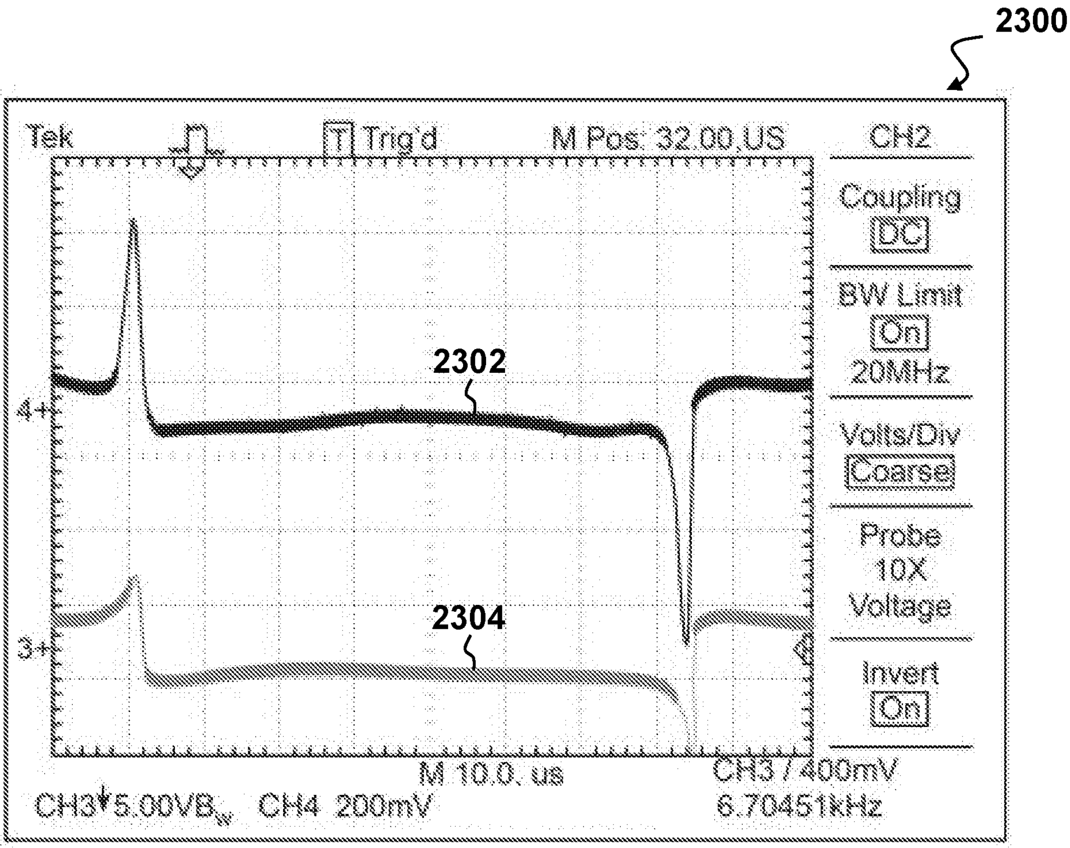

2300
Tek
Trig'd
M Pos: 32.00,US
CH2
Coupling
DC
BW Limit
On
20MHz
Volts/Div
Coarse
Probe
10X
Voltage
Invert
On
2302
2304
4
3
M 10.0. us
CH3 / 400mV
CH3 5.00VBw CH4 200mV
6.70451kHz

FIG. 23

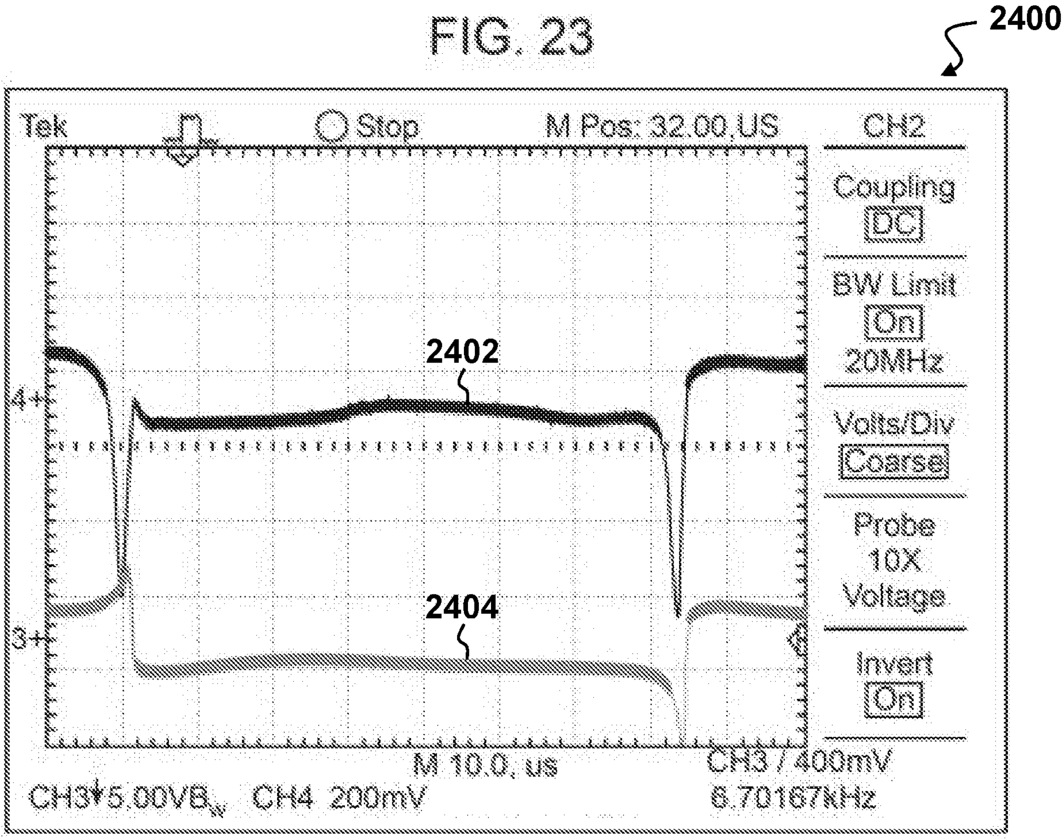

2400
Tek
Stop
M Pos: 32.00,US
CH2
Coupling
DC
BW Limit
On
20MHz
Volts/Div
Coarse
Probe
10X
Voltage
Invert
On
2402
2404
4
3
M 10.0. us
CH3 / 400mV
CH3 5.00VBw CH4 200mV
6.70167kHz

FIG. 24

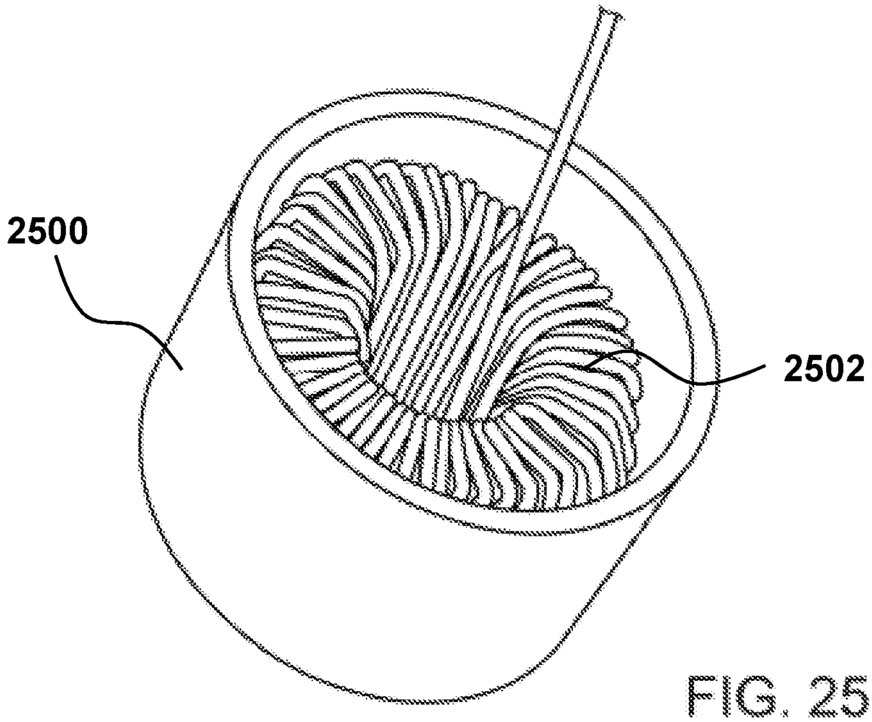


FIG. 25

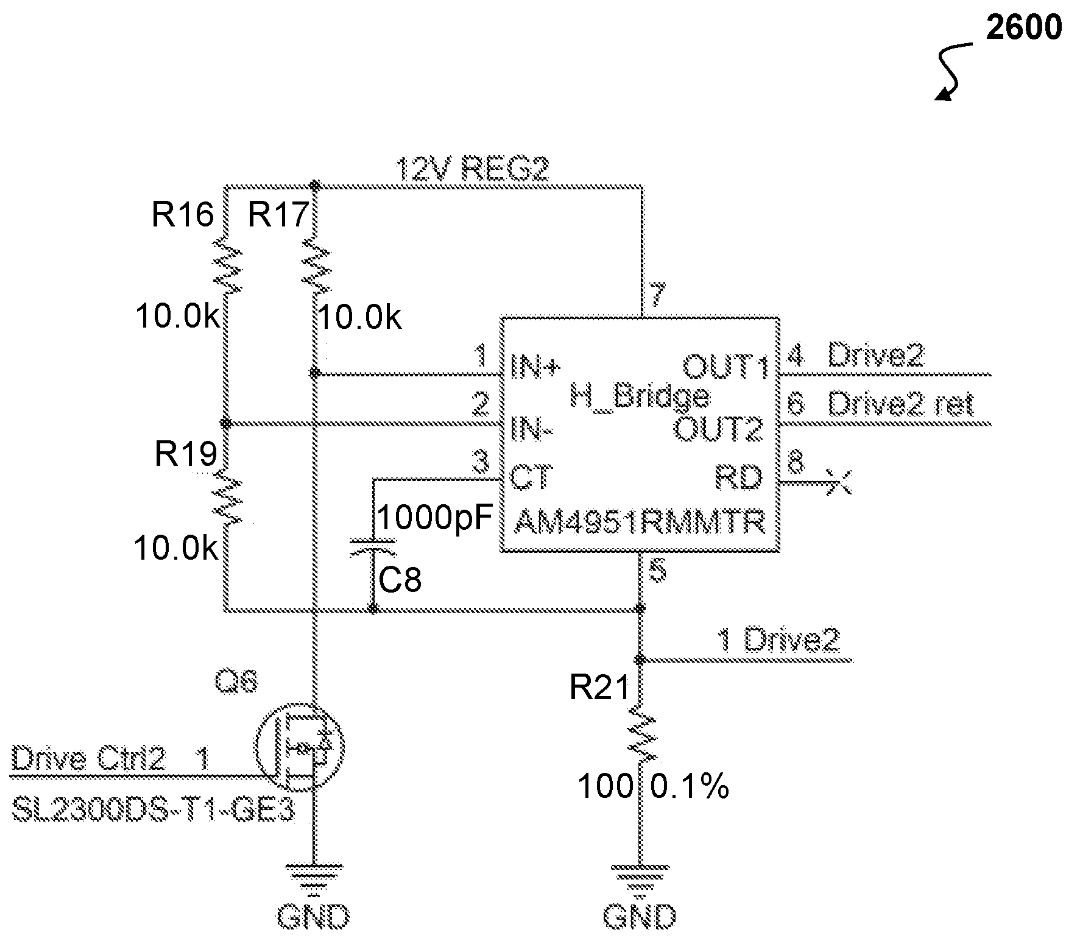

2600
12V REG2
R16
R17
10.0k
10.0k
7
1 IN+
H_Bridge
OUT1 4 Drive2
2 IN-
OUT2 6 Drive2 ret
R19
3 CT
RD 8
1000pF
AM4951RMMTR
10.0k
C8
5
1 Drive2
Q6
R21
Drive Ctrl2 1
SL2300DS-T1-GE3
100 0.1%
GND
GND

FIG. 26

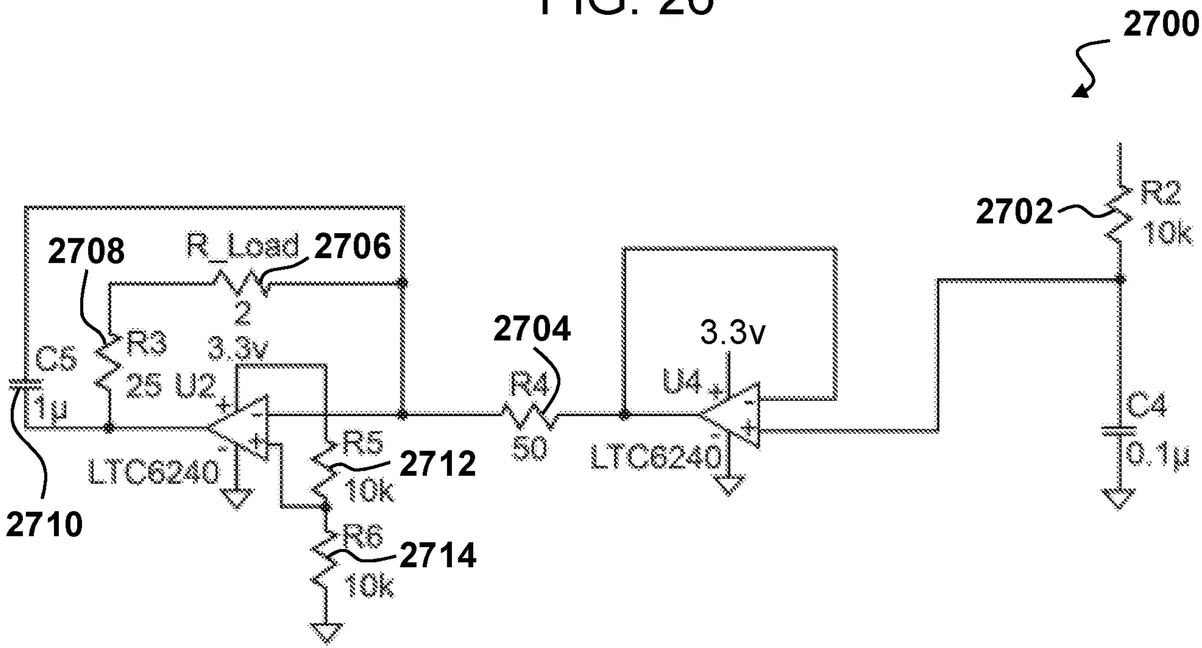

2700
2702
R2
10k
2708
R_Load
2706
2
2704
3.3v
R3
3.3v
C5
25 U2
R4
U4
1µ
50
LTC6240
R5
2712
LTC6240
C4
0.1µ
10k
2710
R6
2714
10k

FIG. 27

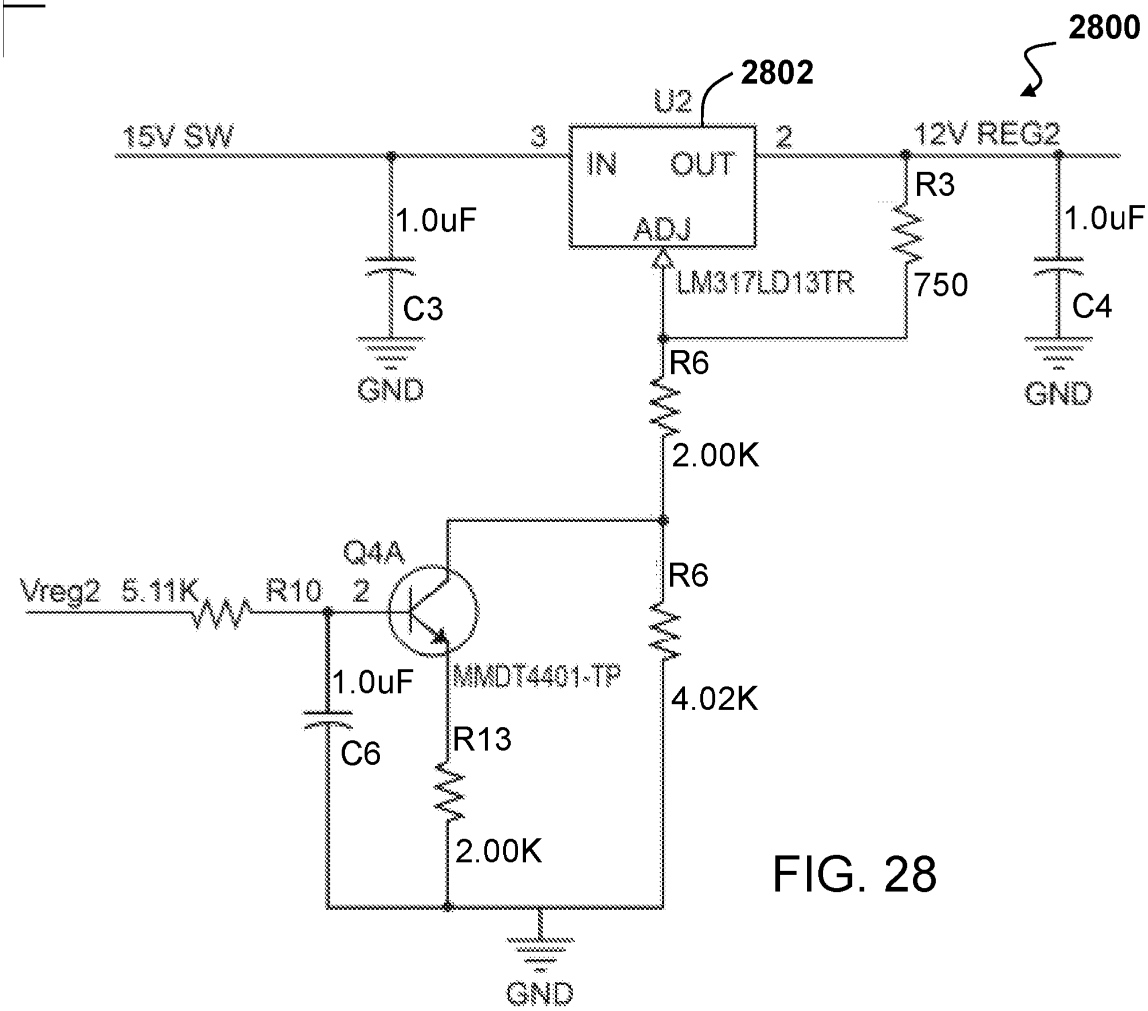

2800
2802
U2
15V SW
3
IN
OUT
2
12V REG2
ADJ
LM317LD13TR
1.0uF
C3
GND
R3
750
1.0uF
C4
GND
R6
2.00K
Q4A
Vreg2
5.11K
R10
2
MMDT4401-TP
1.0uF
C6
R13
2.00K
R6
4.02K
GND

FIG. 28

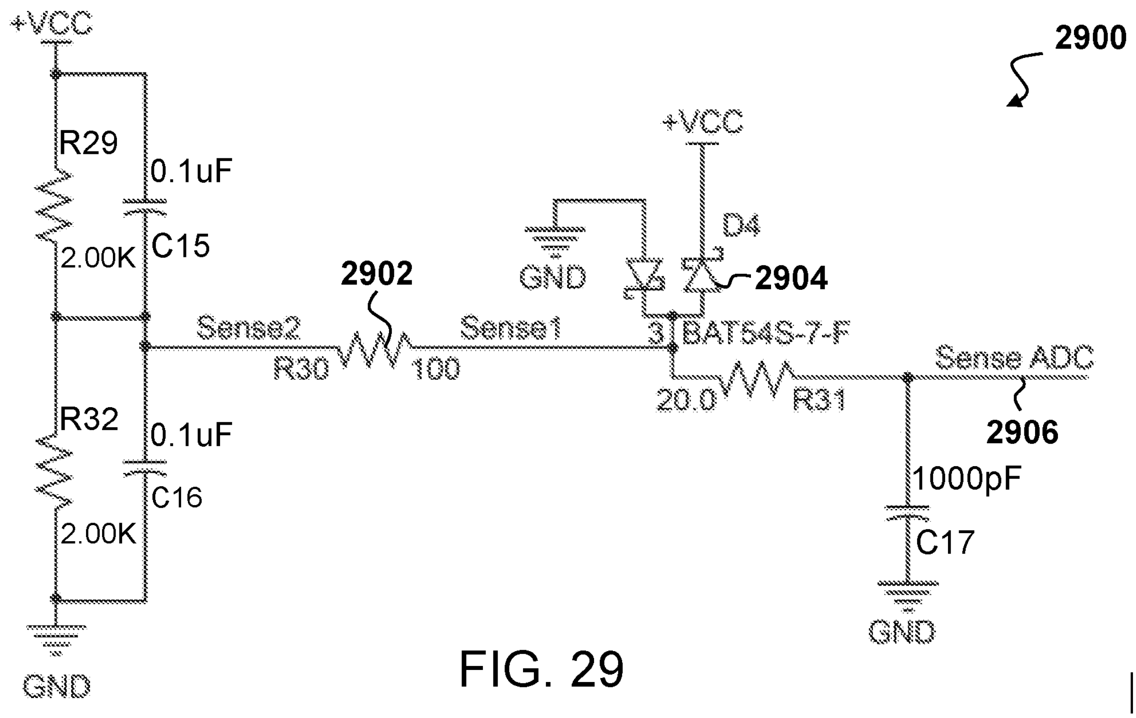

2900
+VCC
R29
2.00K
0.1uF
C15
R32
2.00K
0.1uF
C16
GND
2902
Sense2
R30
100
Sense1
+VCC
D4
GND
2904
3
BAT54S-7-F
20.0
R31
Sense ADC
2906
1000pF
C17
GND

FIG. 29

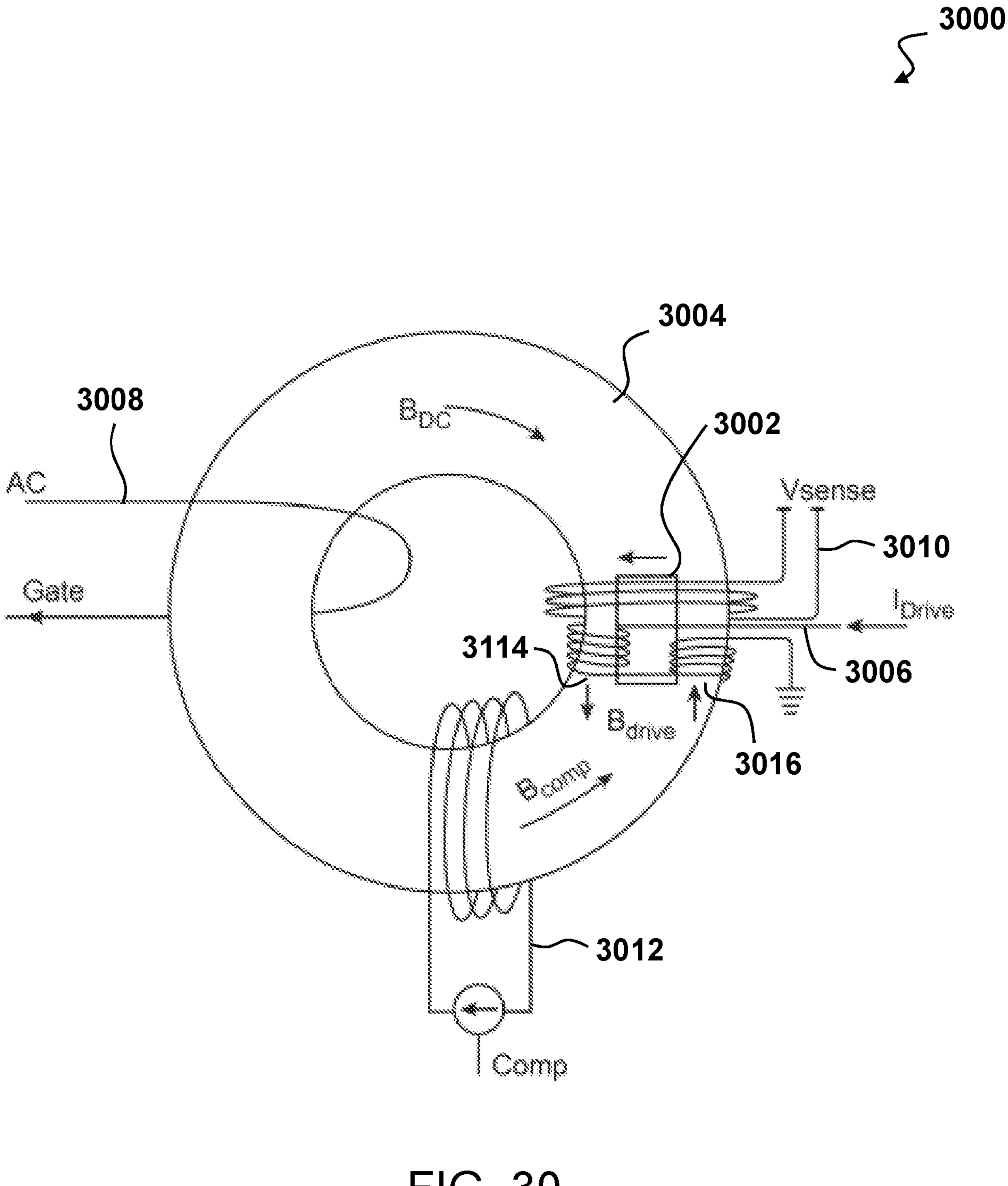

3000
3004
3008
B_DC
3002
AC
Vsense
3010
Gate
I_Drive
3114
3006
B_drive
3016
B_comp
3012
Comp

FIG. 30

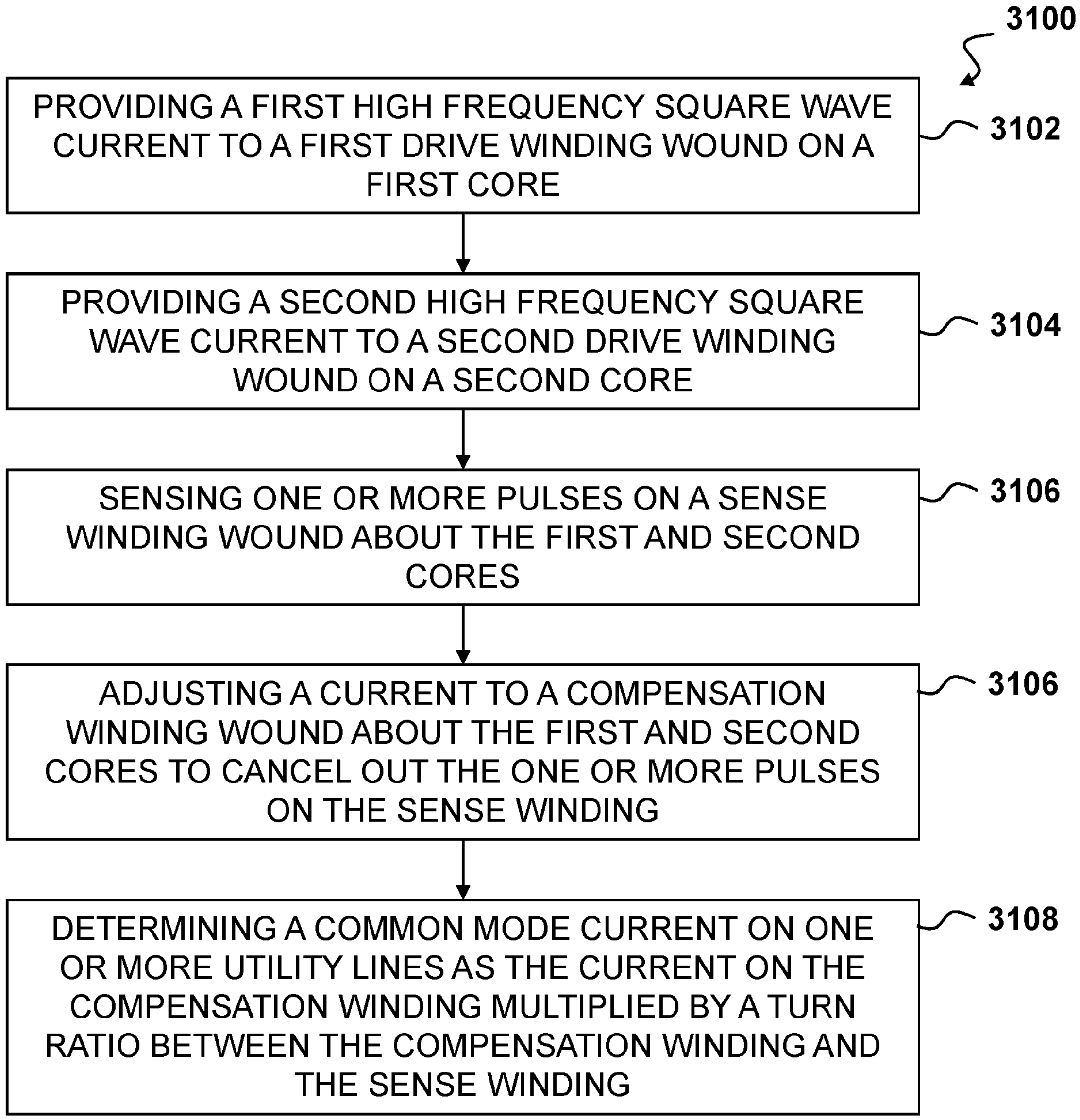

3100
PROVIDING A FIRST HIGH FREQUENCY SQUARE WAVE CURRENT TO A FIRST DRIVE WINDING WOUND ON A FIRST CORE
3102
PROVIDING A SECOND HIGH FREQUENCY SQUARE WAVE CURRENT TO A SECOND DRIVE WINDING WOUND ON A SECOND CORE
3104
SENSING ONE OR MORE PULSES ON A SENSE WINDING WOUND ABOUT THE FIRST AND SECOND CORES
3106
ADJUSTING A CURRENT TO A COMPENSATION WINDING WOUND ABOUT THE FIRST AND SECOND CORES TO CANCEL OUT THE ONE OR MORE PULSES ON THE SENSE WINDING
3106
DETERMINING A COMMON MODE CURRENT ON ONE OR MORE UTILITY LINES AS THE CURRENT ON THE COMPENSATION WINDING MULTIPLIED BY A TURN RATIO BETWEEN THE COMPENSATION WINDING AND THE SENSE WINDING
3108

FIG. 31

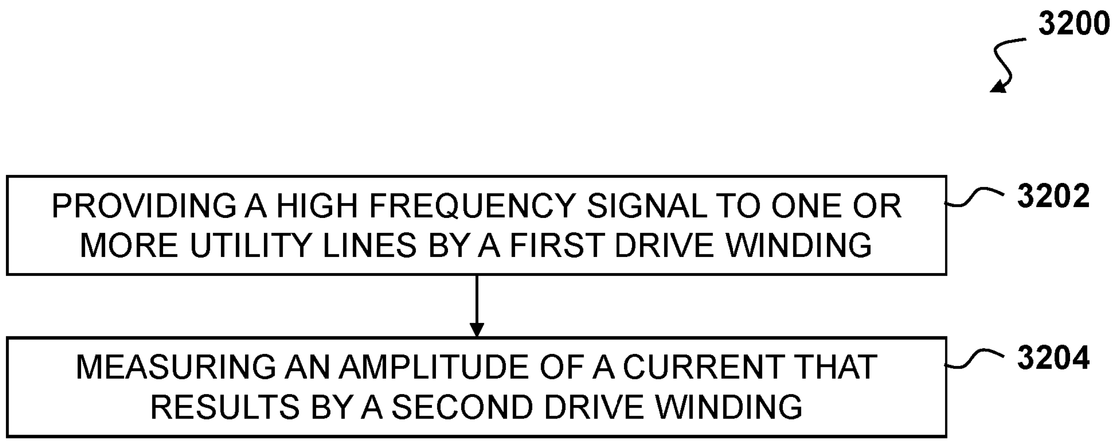

3200
PROVIDING A HIGH FREQUENCY SIGNAL TO ONE OR MORE UTILITY LINES BY A FIRST DRIVE WINDING
3202
MEASURING AN AMPLITUDE OF A CURRENT THAT RESULTS BY A SECOND DRIVE WINDING
3204

FIG. 32

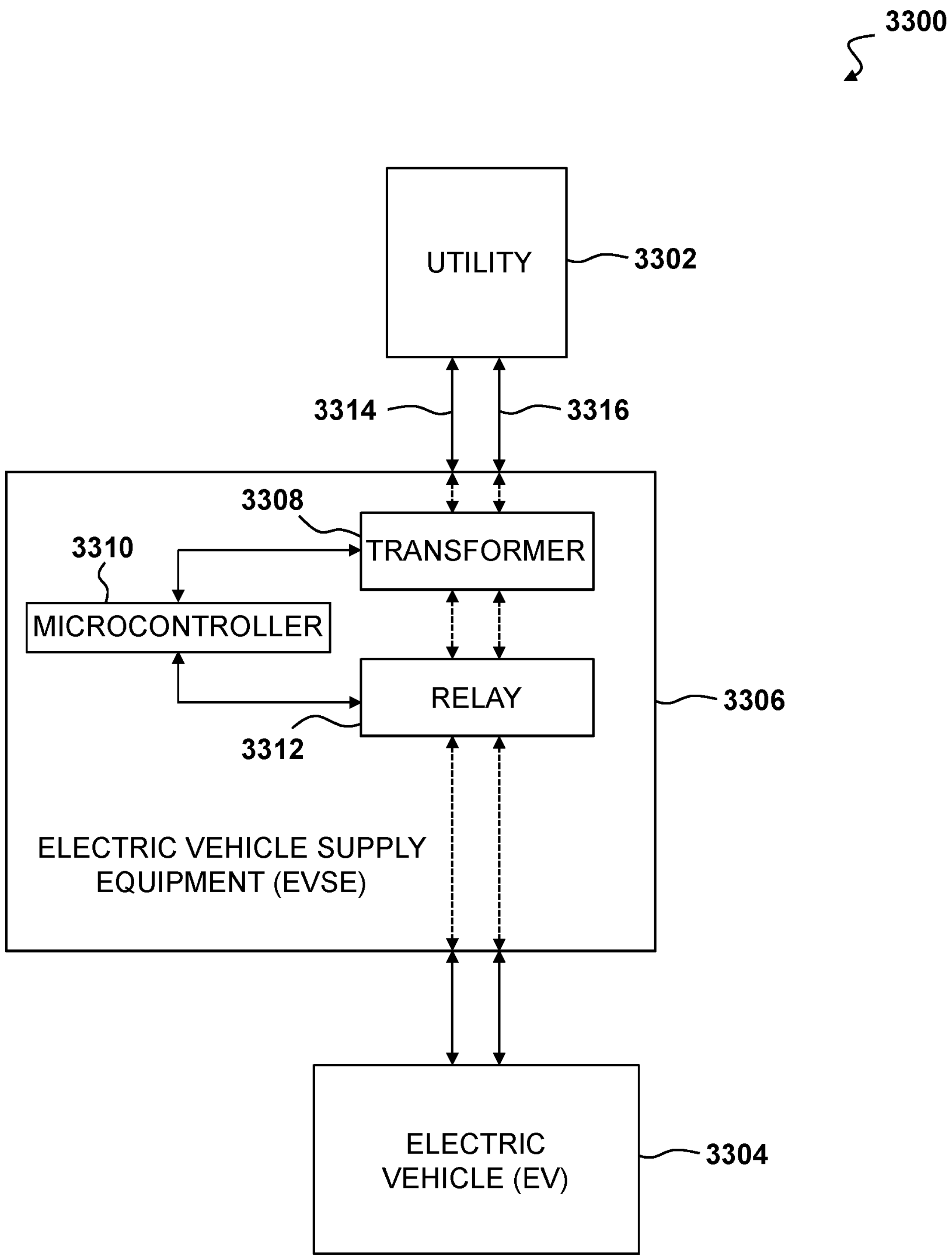

3300
UTILITY
3302
3314
3316
3308
3310
TRANSFORMER
MICROCONTROLLER
RELAY
3306
3312
ELECTRIC VEHICLE SUPPLY EQUIPMENT (EVSE)
ELECTRIC VEHICLE (EV)
3304

FIG. 33

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- DE 3940932 A1 **[0004]**
- WO 2006048020 A1 **[0006]**
- WO 2012160233 A2 **[0006]**
- EP 0137347 A1 **[0007]**
- EP 2749891 A1 **[0007]**
- US 4274051 A **[0008]**

Non-patent literature cited in the description

- **ZHIGANG ZHAO et al.** *The optimization of dual-core closed-loop fluxgate technology in precision current sensor,* 2012 **[0005]**